APPENDIX 5

PRELIMINARY DESIGN OF ROAD AND BRIDGE

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AP5.1 Road Design Standard and Criteria

AP5.1.1 Major Design Elements and Cross-Section Adopted to Various Projects in Cambodia

Table AP.5.1.1 The Major Design Elements Adopted in Major Improvement/Rehabilitation Projects

NR No.	Section	Length (km)	Fund Source*	Year of Implementation	Design Speed (km/h)	Lane Width (m)	Shoulder Width** (m)	Foot-path*** (m)	Type of Pavement	Remarks
1	(i)Phnom Penh ~ Neak Loueng	55	-		80	3.5	(2.5)+1.0	2.5(1.0)	AC	B/D was conducted by GOJ
	(ii) Neak Loueng ~ Vietnam Border	105	ADB	1999 ~ 2003	100	3.8	[1.5]+0.5		DBST	
2	Takeo Center ~ Vietnam Border	52	GOJ	2003 ~ 2005						Counterpart Fund for Non-Project Grant Aid by GOJ
3	(i) Kampot ~ Trapeang Ropov	32.8	GOK	-						Loan Project, Under Construction
	(ii) Trapeang Ropov ~ Veal Rinh	21.5	WB	2001 ~ 2003	-	10****	0.5		DBST	
4	(Sihanouk Ville) ~ Phnom Penh	(220)	USAid	1994 ~ 1995						
5	(i) Phnom Penh ~ Kampong	50	RGC	-						
	(ii) Kampong Chhnang ~ Krakor	50	ADB	2001 ~ 2003						Loan No. 1824
	(iii) Krakor ~ Svay Doun Keo	80	ADB	2000 ~ 2003	60	3.5	[1.5]+0.5		DBST	Loan No. 1697
	(iv) Svay Doun Keo ~ Battambang	50	ADB	2000 ~ 2003	60	3.5	[1.5]+0.5		DBST	Loan No. 1697
	(v) Battambang ~ Sisophon	83	ADB	2001 ~ 2003	60	3.5	[1.5]+0.5		DBST	Loan No. 1824
	(vi) Sisophon ~ Poipet	48.5	ADB	-		3.5				Contractor selecting
6	(i) Phnom Penh ~ Skun	73	ADB	2000 ~ 2003		3.5				Emergency repair
	(ii) Phnom Penh ~ Chueng Chhnok	44	GOJ	1994 ~ 1995	60	3.5	1.5		AC	(Skun-Kampong Cham)
	(iii) Chueng Chhnok ~ Skun	29	GOJ	1998 ~ 1999	60	3.5	1.5-2.0		AC	Together with NR-7
	(iv) Kampong Thom ~ Skun	88	ADB	2001 ~ 2003		3.5				Loan No. 1824
	(v) Prey Romeas ~ Kampong	70	ADB	2000 ~ 2003	60	3.5	[1.5]+0.5		DBST	Loan No. 1697
	(vi) Roluos ~ Prey Romeas	61.1	WB	2001 ~ 2004	-	10****	0.5		DBST	
	(vii) Siem Reap ~ Roluos	17.5	GOJ	2000 ~ 2002	60	3.5	0.5-2.0-2.5		AC	
	(viii) Siem Reap ~ Sisophon	100	ADB	-		3.5				Contractor selecting
7	(i) Skun ~ Kampong Cham	49	GOJ	1998 ~ 1999	60	3.5	1.5-2.0		AC	Together with NR-6
	(ii) Mekong (Kizuna) Bridge	3.34	GOJ	1999 ~ 2002	80	3.5	(1.5)	1.0 (0.9)	AC	Bridge: 1,360 m
	(iii) Kizuna Bridge ~ Thnal Totueng	12	GOJ	2000 ~ 2003	60	3.5	1.0		AC	
	(iv) Thnal Totueng ~ Memot	72	ADB	2000 ~ 2003	60	3.5	[1.5]+0.5		DBST	Loan No. 1697
	(v) Memot ~ Snuol	45	ADB	2001 ~ 2003	60	3.5	[1.5]+0.5		DBST	Loan No. 1824, OPEC Fund extended through ADB
	(vi) Snuol ~ Kratie	83	ADB	2000 ~ 2003	60	3.5	[1.5]+0.5		DBST	Loan No. 1697
	(vii) Kratie ~ Laos Border	198	GOC	2004 ~ 2007						Loan Project

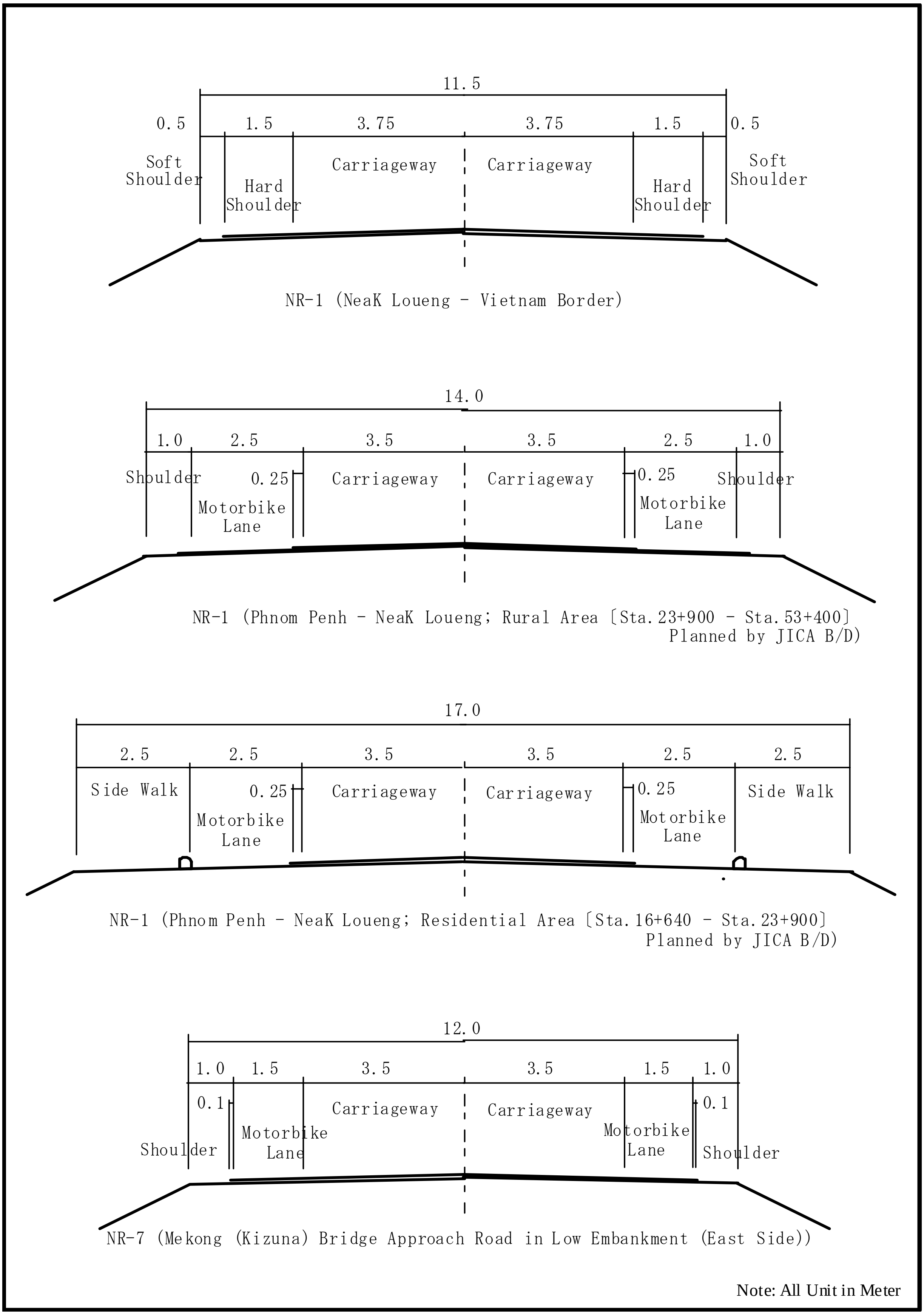
* : Fund Source
ADB: Asian Development Bank, GOJ: Government of Japan, RGC: Royal Government of Cambodia, WB: World Bank, GOK: Government of Korea, GOC: Government of China

** : ( ) shows Motorbike lane width. [ ] shows hard shoulder width .

*** : ( ) shows Footpath width on

**** : Figure shows carriageway width.

Source: Prepared by JICA Study Team



Source: prepared by JICA Study Team.

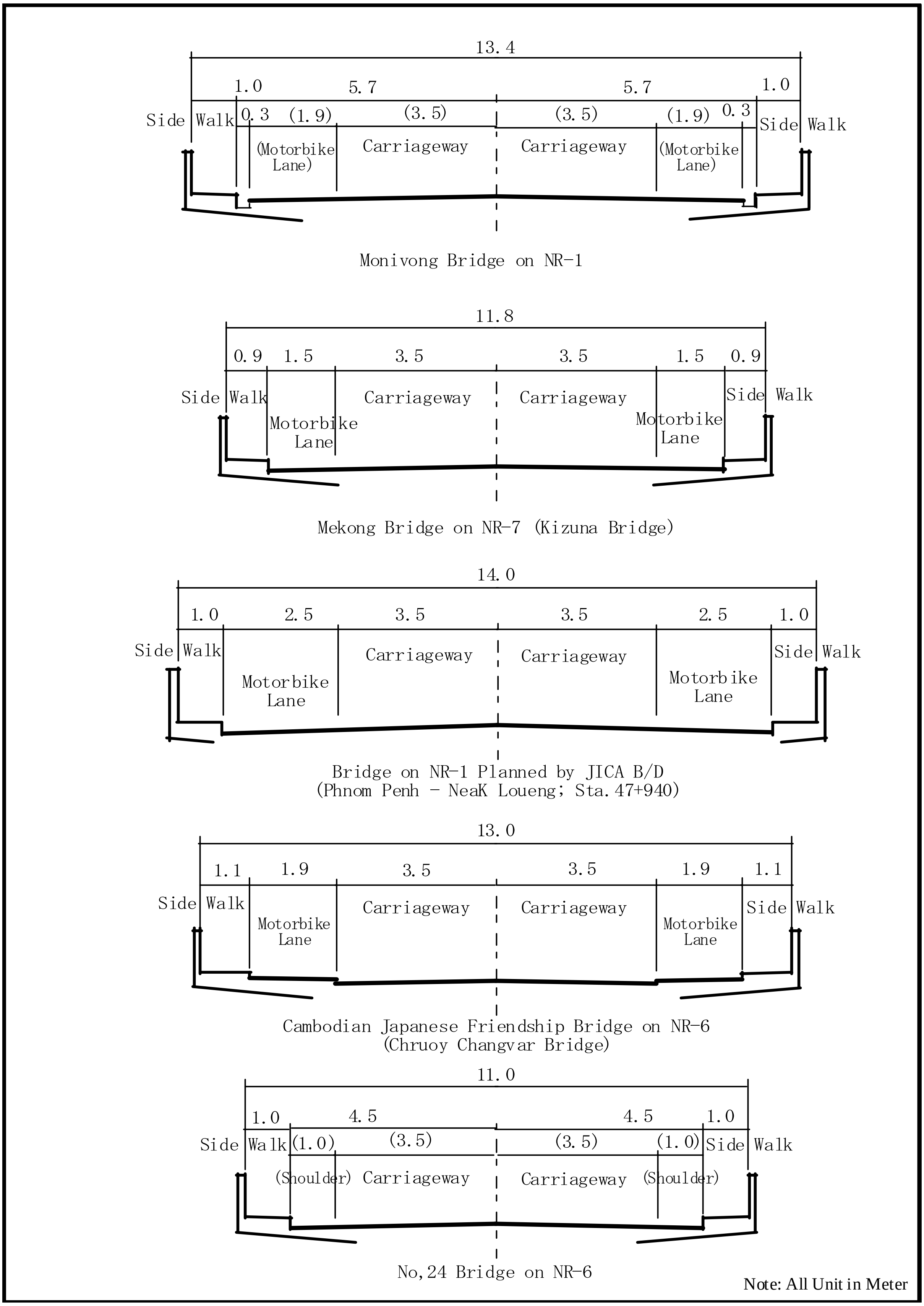
Figure AP.5.1.2 Typical Cross Section on Embankment by Related Projects

Table AP.5.1.2 The Major Design Elements by Donors

Standards		Cambodian		Asian Highway	Japanese		AASHTO	
Highway Classification		Rural Highway	Urban Arterial	Class II	Rural Arterial	Urban Arterial	Rural Arterial**	Urban Arterial***
		R5	U5 (Area Type I)		Category 3, Class 1	Category 4, Class 1		
Terrain		Flat	Flat	Level	Flat	-	Level	Level
Number of Lanes		2	2	2	Depend on Capacity		Depend on Capacity	
Access Control		Partial	Partial	-	Non / Partial	Non / Partial	-	Partial
Design Speed (km/hr)		100	80	80	80	60	100 - 110	60-100
Width (m)	Lane	3.5		3.5	3.5	3.25	3.6	
	Shoulder	3.0		3.0	1.25 (0.75)*	0.5	2.4	1.8
	Marginal Strip	0.5		-	-	-	-	-
	Footpath	-		-	2.0 (1.5-1.0)*	3.5-2.75 (3.0-1.5)*	-	2.4
Pavement Slope (%)		2.5 – 3.0 (Bituminous Concrete)		2.0	1.5		1.5 - 2.0	1.5 - 3.0
Shoulder Slope (%)		3.0 – 4.0 (sealed), 6.0 (earth)		3.0 – 6.0	1.5 (sealed), 3.0 - 5.0 (earth)		1.5 - 2.0	1.5 - 3.0
Min. Horizontal Curve (m)		395 - 415	240 - 255	215	280	150	330	280
Max. Superelevation (%)		6.0 – 7.0		10.0	6.0		12.0	4.0
Max. Vertical Grade (%)		3.0 – 5.0	4.0 – 6.0	4.0	4.0	6.0	3.0	6.0
Type of Pavement		-		AC/CC	AC		Paved	

*: Figures are applied former standard, and ( ) shows on bridge section.
**: Elements shows on design speed of 100km/h.
***: Elements shows on design speed of 80km/h.

Source: Prepared by JICA Study Team



Source: prepared by JICA Study Team.

Figure AP.5.1.2 Typical Cross Section of Major Bridges

AP5.1.2 Sight Distance

Stopping sight distance is the sum of two distances:

- The distance traversed by the vehicles from the instant that the driver sights as object necessitating a stop to the instant that the brakes are applied (Brake Reaction Time); and
- The distance required to stop the vehicle the brake from the instant that brake application begins (Braking Distance).

2.5 seconds is used for the former and the later is dependent on the initial speed and the coefficient of friction between tires and pavement.

The following equation is used for the calculation of stopping sight distance:

$$D = 0.694 \times V + 0.00394 \times V^2 / f$$

where D : Stopping Sight Distance (m)

V : Initial Speed (km/h)

f : Coefficient of Friction between Tires and Pavement

Stopping sight distances by each design speeds on the wet condition are shown in Table AP.5.1.3.

Table AP.5.1.3 Stopping Sight Distance on Wet Pavement

Design Speed (km/h)	Initial Speed		Friction Coefficient on Wet Pavement	Stopping Sight Distance (m)	
	%	km/h		Calculated	Rounded
80	87.5	70	0.31	110.9	110
100	85.0	85	0.30	153.9	160

Source: JICA Study Team.

Sight distance is defined as the distance along a roadway that as object of specified height is continuously visible to the driver with eye-height above the road surface. The height of 1.15 m of driver's eye height on a passenger car is adopted by the Cambodian Standard. The object height on road ranges from 0.1m to 0.2m in international standards. 0.15 m is used as the object height for the Study, which is specified by AASHTO.

Table AP.5.1.4 tabulates the object and driver's eye height specified in the Cambodian Standard and other standards. As far as the Study may concern, only the design element of minimum vertical curve length is affected by this value.

Table AP.5.1.3 Summary of Object and Eye Height Specified

Nations	Japan	AASHTO	Cambodia	The Study
Driver's Eye Height for Stopping (m)	1.2	1.07	1.15	1.15
Object Height (m)	0.1	0.15	0.2	0.15

Source: prepared by JICA Study Team.

Vehicles frequently overtake slower moving vehicles on 2-lane two ways highway such as the study road. The passing must be accomplished on lanes regularly used by opposing traffic. Accordingly, passing sight distance for use in design should be determined on the basis of the length to safely complete normal passing maneuvers.

AASHTO recommends the minimum passing sight distance of 538 m for Vd = 80 km/h. If the design speed should increase up to 100 km/h, it would have to extend to 727 m or more.

Either passing sight distances could not be applicable on 2nd Mekong Bridge, because the bridge length should extend considerably due to applying lager vertical curve, and accordingly no passing / overtaking is allowed.

AP5.1.3 Horizontal Alignment

(1) Maximum Superelevation (i_{max})

As for typical cross section of the study road, a sidewalk physically separated from traveled way is not composed.

Taking every factor into consideration such as traffic features, roadside condition and cross section configuration, maximum superelevation i_{max} = 6.0 % is adopted to the study road.

(2) Minimum Radius (R_{min})

These three factors, i_{max}, R_{min} and i are related each other together with the design speed. The design speeds of 80 km/h is recommended as discussed previously to the study road.

The relation between minimum radius and maximum superelevation is calculated from the following formula.

$$R = \frac{Vd^2}{127 \times (i + f)}$$

where R : Radius (m)

Vd : Design Speed (km/h)

i : Superelevation (m/m)

f : Side Friction Factor

The side friction factors of 0.14 for 80 km/h are accepted as the maximum value in AASHTO, considering comfort of drivers and traffic safety, while the side friction factors of 0.12 are applied in Japanese Standard. In consideration of a lot of vehicles which wears a worn tire, the side friction factors of 0.12 for 80 km/h are selected for the study road.

Absolute maximum side friction factor of 0.4 may be used in order to check the safety on curves assuming that a vehicle is being operated at an excessive speed (20 km/h higher than the design speed i.e. Vd = 100 km/h, when design speed is 80 km/h) as shown in Table AP.5.1.5.

Table AP.5.1.5 Maximum Superelevation and Minimum Radius

Design Speed (km/h)	80
Max. Allowable Side Friction Factor (f)	0.12
Max. Superelevation (i_{max} : %)	6.0
Minimum Radius (m)	280
Side Friction Factor if 20 km/h higher than Vd	0.22
Absolute Max. Side Friction Factor	0.4

Source: JICA Study Team.

The side friction factors f = 0.12 and resulting maximum superelevation i_{max} = 6.0 % are also justified to be applicable to the study road.

(3) Sharpest Curve without Superelevation

Crossfall of 2.0 % applicable to traveled way is mainly determined by drainage requirements. The minimum curvature, which requires superelevation, is determined by setting consistently low friction factor values, considering the effect of crossfall. Side friction factor of 0.035 recommended in the Japanese Standard are used to determine sharpest curve without superelevation as shown in Table AP.5.1.6.

Table AP.5.1.6 Sharpest Curve without Superelevation

Design Speed (km/h)	80
Side Friction Factor (f)	0.035
Crossfall (%)	- 2.0
Sharpest Curve without Superelevation (m)	3,500

Source: JICA Study Team.

(4) Value of Superelevation on Curvature (i)

Table AP.5.1.7 shows value of radius and the resulting superelevation for the design speed.

Table AP.5.1.7 Superelevation related to design speed and horizontal curvature

Superelevation (%)	Horizontal Curvature radius (m)		
	Design Speed: 80km/h		
6.0	280	-	Under 340
5.0	Over 340	-	Under 540
4.0	Over 540	-	Under 850
3.0	Over 850	-	Under 1,500
2.0	Over 1,500	-	Under 3,500

Source: JICA Study Team.

(5) Minimum Transition Curve Length

Transition curves are desirable on high speed roads between circular curves of substantially different radii and between tangents and circular curves.

The length necessary for controlling the steering on a curve is calculated from the following formula, which provides required length for a natural and easy-to-follow path for drivers.

$$L = \frac{Vd}{3.6} \times t$$

where L : Minimum Transition Curve Length (m)

Vd : Design Speed (km/h)

t : Running Time through the Transition Curve (sec.)

Desirable running time through the curve to allow control of the steering is reported to be 3 to 5 seconds. The minimum transition curve length is set 70 m using the running time through the transition curve t = 3 sec and the design speed Vd = 80 km/h.

To make the change of centrifugal acceleration tolerable, the rate of increase of centripetal acceleration (P m/sec^3) is examined by Short's equation where Pmax = 0.56 m/sec^3.

$$P = \frac{\left(\frac{Vd}{3.6}\right)^3}{L \times R}$$

where P : Rate of Increase of Centripetal Acceleration (m/sec^3)

Vd : Design Speed (km/h)

L : Minimum Transition Curve Length (m)

R : Minimum Curve Radius (m)

Table AP.5.1.8 Minimum Transition Curve Lengths and Its Rate of Acceleration

Design Speed (km/h)	80
Running Time (sec.)	3
Minimum Transition Curve Length (m)	70
Minimum Curve Radius (m)	280
Rate of Increase of Centripetal Acceleration (m/sec^3)	0.55 < 0.56

Source: JICA Study Team.

(6) Minimum Horizontal Curve Length

The following values are designated to cover all the horizontal curve lengths, including transition curves if any, and to be of sufficient length for drivers to comfortably adjust their steering to allow for the change in curvature.

Rider Comfort (tolerable limit)

$$L = 0.278 \times Vd \times t$$

where L : Minimum Horizontal Curve Length (m)

Vd : Design Speed (km/h)

t : Minimum Required Steering Time on Curve (sec), t = 6 sec

Table AP.5.1.9 Minimum Horizontal Curve Length (tolerable limit)

Design Speed (km/h)	80
Min. Length Calculated (m)	133
Adopted Value (m)	140

Source: JICA Study Team.

In the cases where the intersection angle (θ) is small, 7° or less, it is desirable to use a longer horizontal curve length than the minimum value. Minimum horizontal curve length is calculated as follows:

Minimum Secant Length, N_{min}

$$N_{min} = \theta_0 \times L / 6 = 0.020 \times L$$

Where

θ_0: Intersection Angle to Govern Min. Secant Length, θ_0=7° = 0.122 rad.

L : Minimum Transition Curve Length (m)

Table AP.5.1.10 Minimum Horizontal Curve Length (N_{min})

Design Speed (km/h)	80
Min. Transition Curve Length (m)	70
Min. Secant Length (m)	1.40

Source: JICA Study Team.

Minimum Horizontal Curve Length, L_{min}

$$L_{min} = 12 \text{ x } N_{min} / \theta \text{ (rad.)} = 688 \text{ x } N_{min} / \theta \text{ (degree)}$$

Table AP.5.1.11 Minimum Horizontal Curve Length (N_{min})

Design Speed (km/h)	80
Min. Secant Length (m)	1.40
Min. Curve Length (m)	1,000/θ

Source: JICA Study Team.

(7) Minimum Radius of Curve not Required Transition Curve

The minimum radius of curve for which no transition curves are required is calculated by using the following formula:

$$R = \frac{1}{24} \text{ x } \frac{L^2}{S} .$$

where S : Shift in Meters between Curve and Tangent (m)
L : Transition Curve Length (m)
R : Radius of Circular Curve (m)

Maximum shift S_{max} = 0.20 applied to the above formula and then minimum radius R_{min} is calculated as follows:

Table AP.5.1.12 Minimum Radius of Curve not Required Transition Curve

Design Speed (km/h)	Min. Transition Curve Length (m)	Min. Radius (m)	
		Calculated	Rounded
80	70	1,021	1,000

Source: JICA Study Team.

(8) Superelevation Runoff

For added comfort and safety, the superelevation runoff should be effected uniformly over a length adequate for the design speed. In other words the length of superelevation runoff should exceed what is specified by the maximum relative slope mentioned below.

$$Q = \frac{3.6 \text{ x } B \text{ x } W}{Vd} \quad .$$

where B : Traveled Way Width from Axle of Rotation (m)
W : Rolling Speed of Vehicle for Profiles (radian/sec.)
Q : Equivalent Maximum Relative Slopes for Profiles (m/m)

At this point, W is applied 6.0m to the calculation, because a motorbike lane width should be contained in a traveled way width.

Table AP.5.1.13 Equivalent Maximum Relative Slopes for Profiles

Design Speed (km/h)		80
B (m)		6.0
W (rad. Sec.)		0.042
Q	Calculated	1:88
	Adopted Value	1:90

Note: The axle of rotation is located at the centerline.
Source: JICA Study Team.

On the contrary, for the requirements of pavement drainage, the length of superelevation runoff in between –2 % and 2 % should not exceed what is computed by the minimum relative slope of 1/300.

The length of 1.2 times as long as the maximum length of superelevation runoff obtained by the minimum relative slope of 1/300 is applied for the study by same reason as previously discussed.

AP5.1.4 Vertical Alignment

(1) Maximum Grade

For design speed of 80 km/h, a maximum grade applied in U.S.A., Japan and Cambodia on flat terrain are compared in Table AP.5.1.14.

Taking into account of traffic characteristics such as over-laden trucks, old vintage trucks and buses and other slow-moving vehicles, maximum grade of 4.0% is adopted for the study road.

Table AP.5.1.14 Comparison of Maximum Grade for Design Speed 80 km/h

Nations	U.S.A.	Japan	Cambodia
Maximum Grade	4.0 %	4.0 %	4.0 – 6.0 %

Note: Value of U.S.A. is applied for a rural arterial road.
Source: Prepared by JICA Study Team.

(2) Minimum Vertical Curve Length and Radius

Vertical curves effect gradual change between tangent grades in crest and sag curves and should result in a design that is safe, comfortable in operation, pleasing in appearance and adequate for drainage.

The major control for safe operation on crest vertical curves is the provision of ample sight distance for the design speed and rider comfort, while headlight sight distance and rider comfort govern the length of sag vertical curve.

The following equations are used for the calculation of required vertical curve length and radius of vertical curve, of which longer length is applicable.

A. Rider Comfort (Tolerable Limit)

$$L = \frac{Vd}{3.6} \times t$$

where L : Vertical Curve Length (m)
Vd : Design Speed (km/h)
t : Minimum Required Time, t = 3 sec.

Table AP.5.1.15 Minimum Vertical Curve Length (tolerable limit)

Design Speed (km/h)	80
Min. Length Calculated (m)	67
Rounded Value (m)	70

Source: JICA Study Team.

B. On Crest Curve (Object height: 0.15 m, Eye Height: 1.15 m)

$$L = \frac{D^2 \times i}{426} \quad \text{OR} \quad R = \frac{100 \times D^2}{426}$$

where L : Vertical Curve Length (m)
D : Sight Distance (m)
R : Radius of Vertical Curve (m)
i : Algebraic Difference in Grade (%)

As discussed previously, the design speed of 80 km/h is recommended to the study road. However, the following comparison may ascertain its justification.

Table AP.5.1.16 Minimum Vertical Curve Radius on Crest Curve

Design Speed (km/h)	Sight Distance (m)	On Crest Curve (m)	
		Min. Vertical Curve Length	Min. Radius
80	110	230	2,850

Note: The computation is made on the condition that the algebraic difference of maximum grades.
Source: JICA Study Team.

C. On Sag Curve

(Headlight Sight Distance: Headlight Height = 0.75m, Angle = 1°)

$$L = \frac{D^2 \text{ x } i}{150 + 3.5 \text{ x } D} \quad \text{OR} \quad R = \frac{100 \text{ x } D^2}{150 + 3.5 \text{ x } D}$$

where L : Vertical Curve Length (m)

D : Sight Distance (m)

R : Radius of Vertical Curve (m)

i : Algebraic Difference in Grade (%)

Table AP.5.1.17 Minimum Vertical Curve Radius on Sag Curve

Design Speed (km/h)	Sight Distance (m)	On Crest Curve (m)	
		Min. Vertical Curve Length	Min. Radius
80	110	190	2,300

Note: The computation is made on the condition that the algebraic difference of maximum grades.
Source: JICA Study Team.

The calculation result of minimum vertical curve length for the major algebraic difference in grade is shown Table AP.5.1.18. As understood from this calculation result, minimum vertical curve length is determined by the rider comfort. Therefore, minimum vertical curve length of 70m is adopted for the study road.

Table AP.5.1.18 Calculation Result of Minimum Vertical Curve Length

Algebraic Difference in Grade (%)	Minimum Vertical Length (m)					
	On Crest Curve			On Sag Curve		
	Rider Comfort	Sight Distance	Adopt Value	Rider Comfort	Sight Distance	Adopt Value
8.0	70	227	230	70	181	190
7.5	70	213	220	70	170	170
7.0	70	199	200	70	158	160
6.5	70	185	190	70	147	150
6.0	70	170	180	70	136	140
5.5	70	156	160	70	124	130
5.0	70	142	150	70	113	120
4.5	70	128	130	70	102	110
4.0	70	114	120	70	90	100
3.5	70	99	100	70	79	80
3.0	70	85	90	70	68	70
2.5	70	71	80	70	57	70
2.0	70	57	70	70	45	70
1.5	70	43	70	70	34	70
1.0	70	28	70	70	23	70
0.5	70	14	70	70	11	70

Source: JICA Study Team.

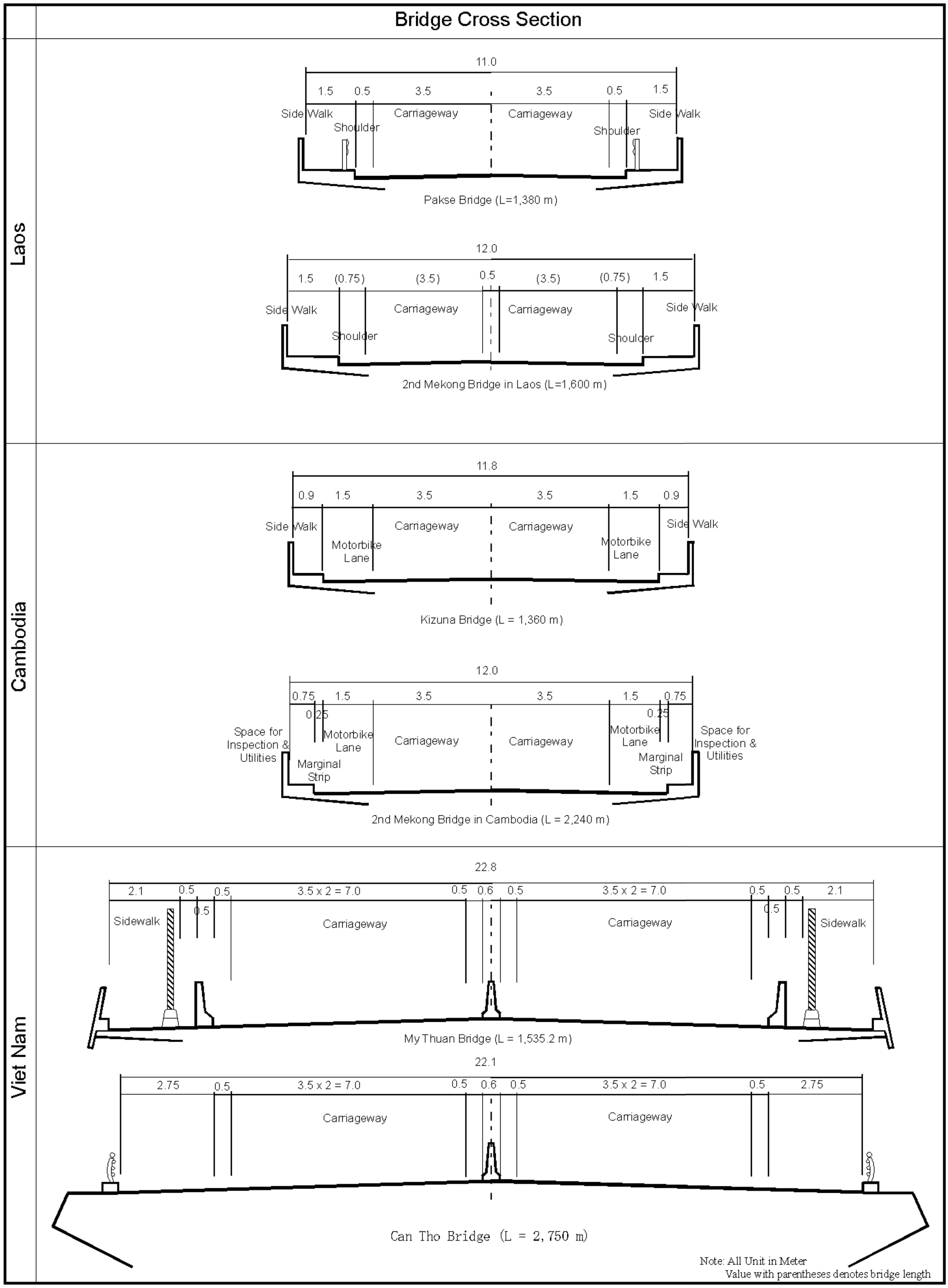
AP5.1.5 Comparison of Major Design Criteria with Related Projects and of Cross-Section over the Mekong River

Table AP.5.1.19 Comparison of Major Geometric Design Criteria between Study Recommendation, Related Projects and Donors

Items			Study Recommendation	Project			Donor & Nation			
				Phnom Penh ~ Neak Loueng	Neak Loueng ~ Vietnam Border	Mekong (Kizuna) Bridge	Asian Highway	AASHTO	Japanese	Cambodian
				Sta.23+900 ~ Sta.53+400	KM62+010 ~ KM167+470		Class II	Rural Arterial (Level)	Category 3,Class 1	U5
Number of Lanes			2	2	2	2	2	Depend on Capacity	Depend on Capacity	2
Design Speed (km/hr)			80	80	100	80	80	80	80	80
Width (m)	Embankment	Lane	3.50	3.50	3.75	3.50	3.50	3.60	3.50	3.50
		Motorbike	2.50	2.50	-	1.50	-	-	-	-
		Shoulder	1.00	1.00	1.50[3]+0.50	1.50	3.00	2.40	1.25	3.00
		Marginal Strip	0.25	0.25	-	0.10	-	-	-	0.50
		Sidewalk	-	-	-	-	-	-	1.50[7]	-
		Total	14.00	14.00	11.50	13.00	13.00	12.00	12.50	13.00
	Bridge	Lane	3.50	3.50	N.A.	3.50	N.A.	N.A.	3.50	N.A.
		Motorbike	1.50	2.50		1.50			-	
		Shoulder	0.25[1]	-		-			0.75	
		Sidewalk	0.75[2]	1.00		0.90			1.00[7]	
		Total	12.00	14.00		11.80			10.50	
Pavement Slope (%)			2.0	3.0	3.0	2.0 (1.5[5])	2.0	1.5 - 2.0	1.5 - 2.0	2.5 – 3.0
Soft Shouler Slope (%)			4.0	4.0	6.0	2.0	3.0 – 6.0	1.5 - 2.0	3.0 - 5.0	6.0
Max. Superelevation (%)			6.0	4.0	5.5[4]	4.0[4]	10.0	6.0	6.0	6.0 – 7.0
Abs. Min. Horizontal Curve (m)			280	280	500	250	215	250	280	240 - 255
Min. Transsition Curve Length (m)			70	70	-	-	70	Computing	70	45 - 90
Max. Vertical Grade (%)			4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0 – 6.0
Min. Vertical Crest Curve (m)			2,850	-	5,500	-	-	4,900[6]	3,000	3000[6]
Min. Vertical Sag Curve (m)			2,300	-	2,000	-	-	3,200[6]	2,800	2800[6]
Type of Pavement			AC	AC	DBST	AC	AC/CC	Paved	AC	Bituminous

Note:
1): Marginal Strip　2): Space for inspection & utilities　3): Hard shoulder　4): Applied at Min. horizontal curve in actural
5): On bridge　6): R=100xK　7): Figures are applied former standard

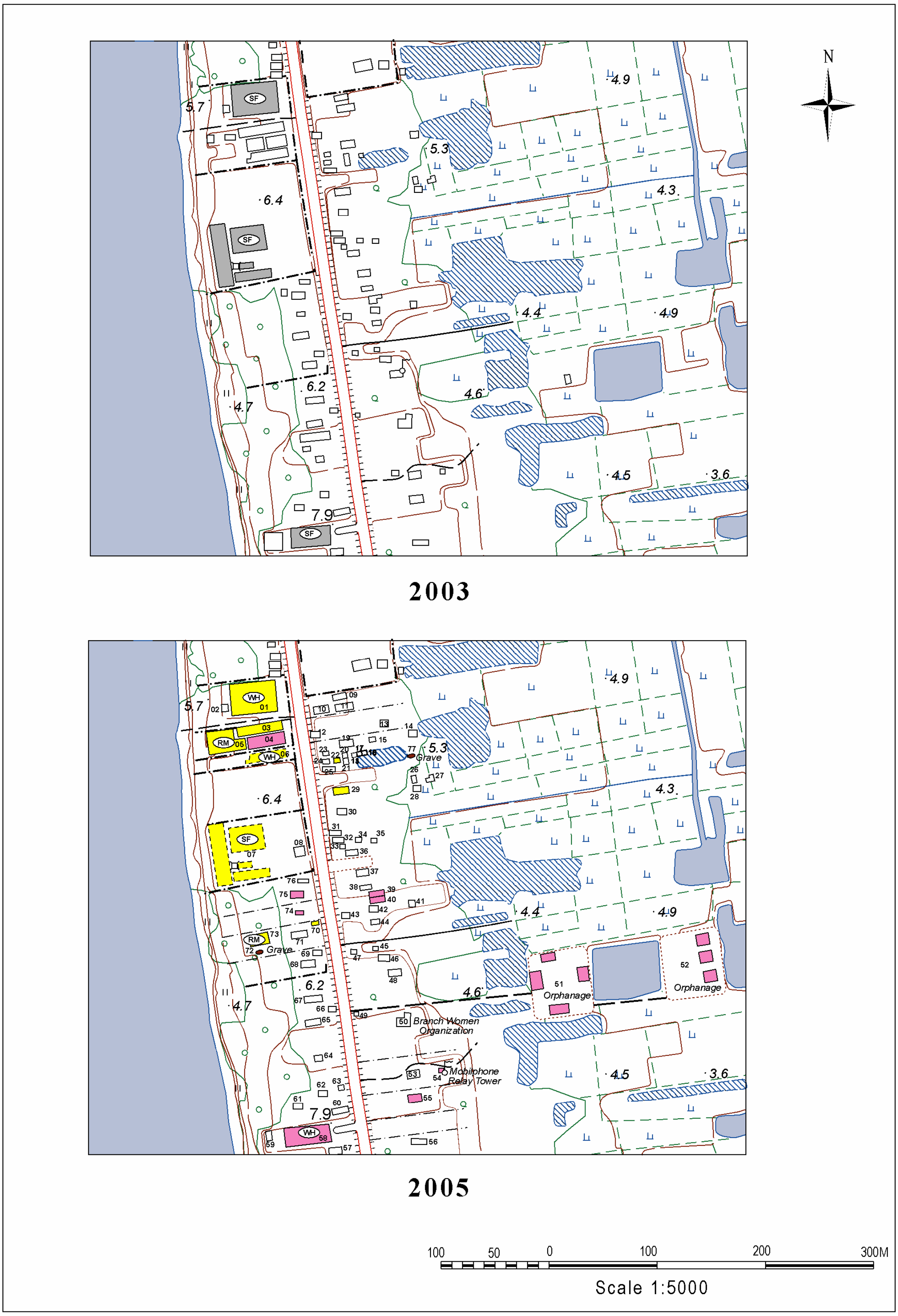
Source: Prepared by JICA Study Team



Source: JICA Study Team.

Figure AP.5.1.3 Bridge Cross Section over the Mekong River

AP 5.2 Scrutiny of the Selected Route and the Location of the Bridge



Source: Prepared JICA Study Team.

Figure AP 5.2.1 Comparison of Topographic Map by Year 2003 and 2005

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Source: JICA Study Team.

AP5.3 Highway Engineering Design

AP5.3.1 Type and Location of Intersections

(1) Traffic Control Method at Major Intersections

Traffic control method is studied for major intersections of the west and east intersections, Memorial Park Intersection and Toll Gate Intersection. Traffic control Method is divided broadly into two types, that is a signalized intersection and an un-signalized intersection. As the result of the study, all the intersections on the project road are recommended to apply the un-signalized TWSC (Two-Way Stop-Controlled) method. At first, it is examined whether or not the un-signalized intersection is applicable for the major intersections.

Unsignalized intersection is classified into three types as follows:

- Two-Way Stop-Controlled Intersections (TWSC Intersections)
- All-Way Stop-Controlled Intersections (AWSC Intersections) and
- Roundabout

TWSC Intersection is suitable for the major intersection in the Study, because the relationship between major road and minor road is clear. Therefore, the major intersections are examined as TWSC Intersections.

The capacity of TWSC Intersections is calculated based on the sum of the following two traffic volumes:

- General traffic volumes of the major or priority road and,
- Maximum traffic volume of the minor or non-priority road that at the same time possibly can pass through the intersection after one stopping.

Accordingly, the usage of headways in priority traffic flow by vehicles of non-priority traffic flow is generally treated under the “gap-acceptance”. The simple model equation is given by Poisson distribution:

$$Q_{max} = Q\, e^{-\mu t_1} / (1- e^{-\mu t_2})$$

where, Q_{max} = Maximum volume of minor road vehicles that can pass (veh/h)

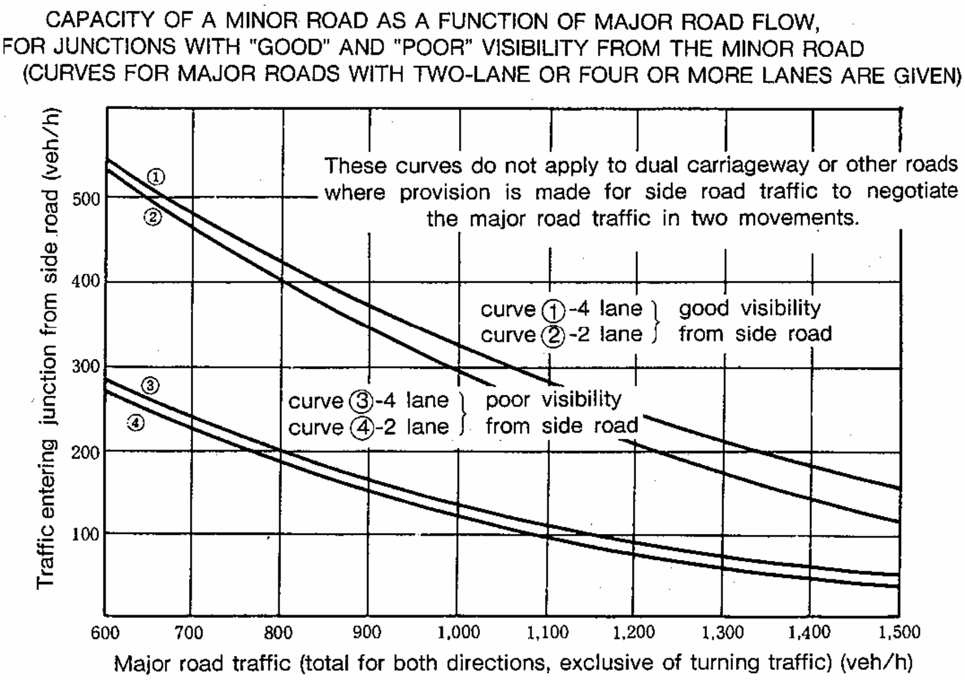
Q = Given volume of major road (veh/h), both directions

μ = Q/3600

t_1= Minimum time gap necessary in a major traffic flow to allow crossing by minor road vehicles

t_2= Average headway between minor road vehicles which cross as platoons

Figure AP5.3.1, based on the above equation, is used in England for examination of traffic capacity at an unsignalized intersection.



Source: The Planning and Design of At-Grade Intersections, Japan Society of Traffic Engineers.

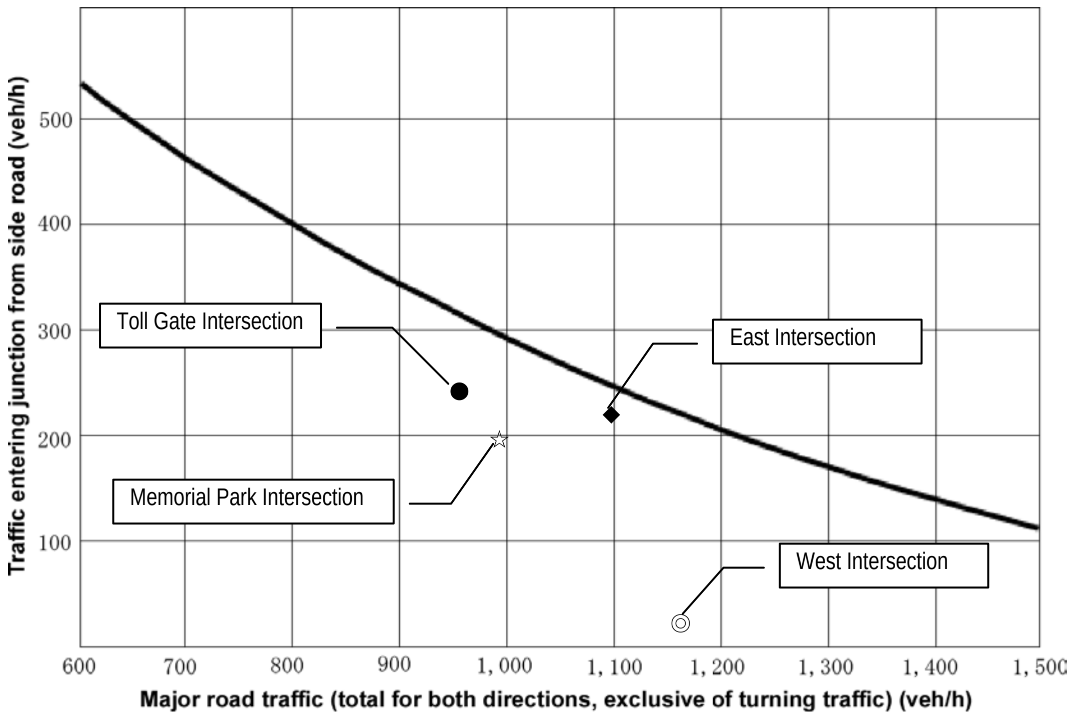
Figure AP5.3.1 Traffic Capacity at TWSC Intersections

Based on Figure AP5.3.1, the relationship between traffic capacity and traffic volume at each major intersections is identical as shown in Figure AP5.3.1. The following conditions underlie Figure AP5.3.1.

- Future traffic volume in year 2020,
- Good visibility from minor road,
- Major road with 2 lane and,
- Applying left turning traffic only from minor road of channelized intersection.

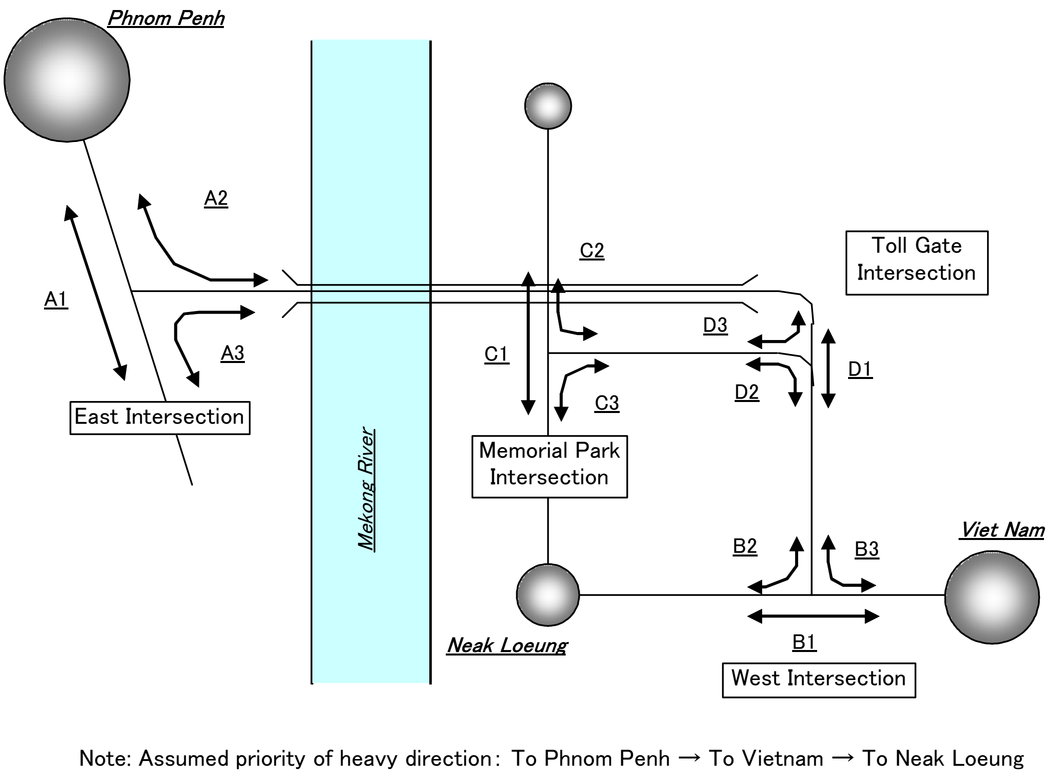
Traffic volume of right turning from minor road is ignored at channelized intersection because traffic movement of right turning from minor road is similar to interchange ramp terminals and unsuitable to apply.

According to Figure AP5.3.2, the traffic volume at each intersection is less than the traffic capacity. Therefore, major intersections will be operated as unsignalied intersection (TWSC Intersection).



Source: JICA Study Team

Figure AP5.3.2 Comparison between Traffic Capacity and Traffic Volume at Major Intersections



Source: JICA Study Team.

Figure AP.5.3.3 Map of Major Intersections

Table AP.5.3.1 Traffic Volume at Major Intersections

Unit: Vehicle/day

Intersection	Direction	MC	LV	HV	Total
East	A1	2,198	814	30	3,042
	A2	4,496	3,904	718	9,118
	A3	237	205	38	480
West	B1	4,805	455	78	5,338
	B2	142	123	23	288
	B3	5,534	3,453	633	9,620
Memorial Park	C1	6,429	1,306	585	8,320
	C2	2,552	863	156	3,572
	C3	0	0	0	0
Toll Gate	D1	3,928	3,411	627	7,967
	D2	1,748	165	28	1,941
	D3	804	698	128	1,631

Source: JICA Study Team.

Table AP.5.3.2 Traffic Volume by Peak Hour

Unit: Vehicle/hour

Intersection	Direction	MC	LV	HV	Total
East	A1	264	98	4	366
	A2	539	468	86	1,093
	A3	28	25	5	58
West	B1	577	55	9	641
	B2	17	15	3	35
	B3	664	414	76	1,154
Memorial Park	C1	771	157	70	998
	C2	306	104	19	429
	C3	0	0	0	0
Toll Gate	D1	471	409	75	955
	D2	210	20	3	233
	D3	96	84	15	195

Note: Peak hourly ratio of 0.12 is applied.
Source: JICA Study Team.

Table AP.5.3.3 Traffic Volume by Direction

Unit: Vehicle/hour/direction

Heavey Direction	Intersection	Intersection Direction	MC	LV	HV	Total	Code No.
To PP	East	A1	149	55	2	206	A1-M
		A2	305	264	49	618	A2-M
		A3	16	14	3	33	A3-M
	West	B1	326	31	5	362	B1-M
		B2	10	8	2	20	B2-M
		B3	375	234	43	652	B3-M
	Memorial Park	C1	436	89	40	565	C1-M
		C2	173	59	11	243	C2-M
		C3	0	0	0	0	C3-M
	Toll Gate	D1	266	231	42	539	D1-M
		D2	119	11	2	132	D2-M
		D3	54	47	8	109	D3-M
From PP	East	A1	115	43	2	160	A1-S
		A2	234	204	37	475	A2-S
		A3	12	11	2	25	A3-S
	West	B1	251	24	4	279	B1-S
		B2	7	7	1	15	B2-S
		B3	289	180	33	502	B3-S
	Memorial Park	C1	335	68	30	433	C1-S
		C2	133	45	8	186	C2-S
		C3	0	0	0	0	C3-S
	Toll Gate	D1	205	178	33	416	D1-S
		D2	91	9	1	101	D2-S
		D3	42	37	7	86	D3-S

Note: Heavy direction ratio of 0.565 is applied.
Source: JICA Study Team.

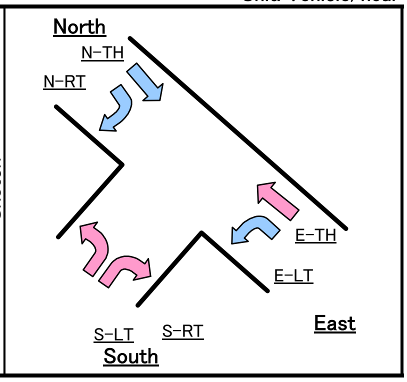
Table AP.5.3.4 Traffic Volume for Intersection Analysis

East Intersection

Unit: Vehicle/hour

IN-FLOW	Direction	MC	LV	HV	Total	HV Rate	Code No.
North	N-TH	234	204	37	475	8%	A2-S
	N-RT	115	43	2	160	1%	A1-S
	Sub-T	349	247	37	635	6%	
East	E-LT	12	11	2	25	8%	A3-S
	E-TH	305	264	49	618	8%	A2-M
	Sub-T	317	275	51	643	8%	
South	S-LT	149	55	2	206	1%	A1-M
	S-RT	16	14	3	33	9%	A3-M
	Sub-T	165	69	2	239	1%	
Major road traffic without turning traffic					1,093		
Traffic entering junction from side road					206	Excluding right turn	

Sketch

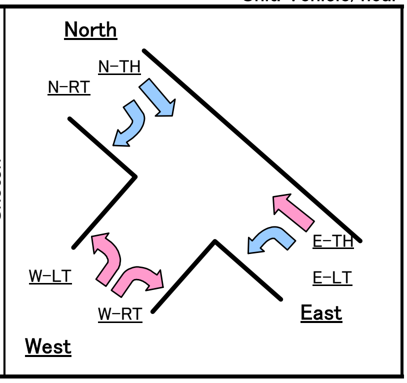


West Intersection

Unit: Vehicle/hour

IN-FLOW	Direction	MC	LV	HV	Total	HV Rate	Code No.
North	N-TH	289	180	33	502	7%	B3-S
	N-RT	7	7	1	15	7%	B2-S
	Sub-T	296	187	34	517	7%	
East	E-LT	251	24	4	279	1%	B1-S
	E-TH	375	234	43	652	7%	B3-M
	Sub-T	626	258	43	931	5%	
West	W-LT	10	8	2	20	10%	B2-M
	W-RT	326	31	5	362	1%	B1-M
	Sub-T	336	39	2	382	1%	
Major road traffic without turning traffic					1,154		
Traffic entering junction from side road					20	Excluding right turn	

Sketch

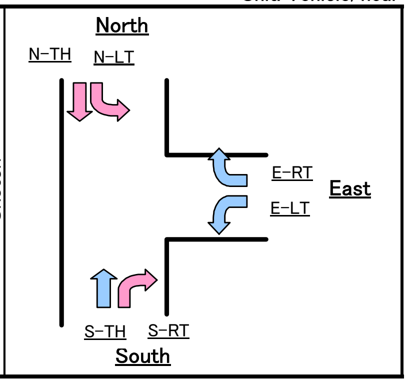


Memorial Park Intersection

Unit: Vehicle/hour

IN-FLOW	Direction	MC	LV	HV	Total	HV Rate	Code No.
North	N-LT	173	59	11	243	5%	C2-M
	N-TH	436	89	40	565	7%	C1-M
	Sub-T	609	148	11	808	1%	
East	E-LT	0	0	0	0	-	C3-S
	E-RT	133	45	8	186	4%	C2-S
	Sub-T	133	45	8	186	4%	
South	S-TH	335	68	30	433	7%	C1-S
	S-RT	0	0	0	0	-	C3-M
	Sub-T	335	68	0	433	0%	
Major road traffic without turning traffic					998		
Traffic entering junction from side road					186		

Sketch

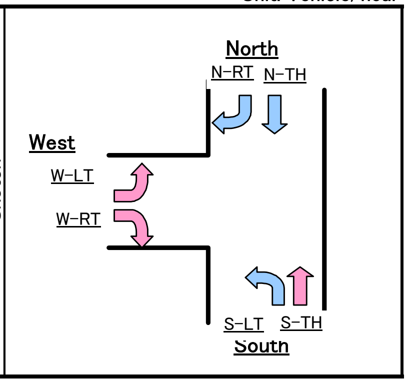


Toll Gate Intersection

Unit: Vehicle/hour

IN-FLOW	Direction	MC	LV	HV	Total	HV Rate	Code No.
North	N-TH	205	178	33	416	8%	D1-S
	N-RT	42	37	7	86	8%	D3-S
	Sub-T	247	215	40	502	8%	
South	S-LT	91	9	1	101	1%	D2-S
	S-TH	266	231	42	539	8%	D1-M
	Sub-T	357	240	42	640	7%	
West	W-LT	54	47	8	109	7%	D3-M
	W-RT	119	11	2	132	2%	D2-M
	Sub-T	173	58	10	241	4%	
Major road traffic without turning traffic					955		
Traffic entering junction from side road					241		

Sketch



Note: (pink arrow) : Major Direction (blue arrow) : Minor Direction

Source: JICA Study Team.

AP5.3.2 Pavement

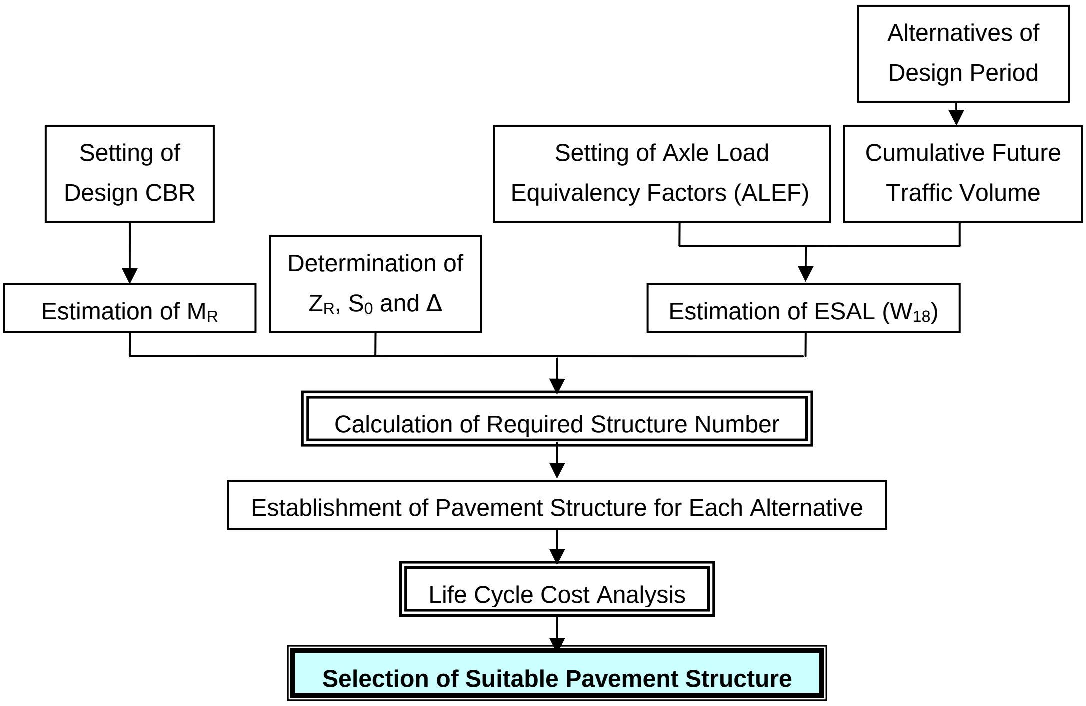
(1) Main Road (NR-1)

1) Design Criteria

"Design Guide for Pavement Structure" of AASHTO is adopted as the design criteria for the Study, because AASHTO Standard is widely accepted in many countries. Other relevant standards/manuals, such as "Manual for Asphalt Pavement" of Japan Road Association (JRO) and "Road Design Standard; Part II Pavement" of Cambodia are referred as appropriate.

2) Methodology of Pavement Design

Outline procedure of pavement design for the Study using "Design Guide for Pavement Structure" is shown in Figure AP5.3.4.



Source: JICA Study Team

Figure AP5.3.4 General Flow of Pavement Design

In AASHTO Standard, required Structure Number (SN) which means required pavement strength is calculated by the following formula:

$$\mathrm{Log}_{10} W_{18} = Z_R{*}S_0 + 9.36{*}\log_{10}(SN+1) - 0.20 + \frac{\mathrm{Log}_{10}\{\Delta PSI/(4.2 - 1.5)\}}{0.40 + 1094/(SN+1)^{5.19}} + 2.32{*}\log_{10} M_R - 8.07$$

Where;

W_{18} = predicted number of 18-kip equivalent single axle load applications,

Z_R = standard normal deviate,

S_0 = combined standard error of the traffic prediction and performance prediction,

$\angle$PSI = difference between the initial design serviceability index, p_0, and the design terminal serviceability index, p_t, and

M_R = resilient modulus (psi) (of subgrade).

3) Setting of Alternatives of Design Period

The design period of the pavement is applied 10 years as the standard value in the Manual of JRO. For the Life Cycle Cost Analysis (LCC Analysis), three alternatives of design period were set as shown in Table AP5.3.5.

Table AP5.3.5 Alternatives of Design Period

Alternatives	Design Period
ALT-1	7 years
ALT-2	10 years
ALT-3	13 years

Source: JICA Study Team

4) Estimation of Equivalent Single Axle Load (W_{18})

Number of 18 kips single axle load application, W_{18}, was estimated from cumulative future traffic volume and Axle Load Equivalency Factor (ALEF).

W_{18} = Cumulative Traffic Volume (for design period) x ALEF

Future traffic volume forecasted in Chapter 3 was used to calculate the cumulative traffic volume.

Values of ALEF for type of vehicles were applied as same as values of the Basic Design on the Project for the Improvement of National Road No.1 conducted by JICA. Applied ALEF for light vehicles and heavy vehicles are as shown in Table AP5.3.6.

Table AP5.3.6 Applied Values of ALEF

Vehicle Type	Light Vehicle	Heavy Vehicle
ALEF	0.0036	1.89

Source: Basic design study report on the project for the improvement of NR-1, JICA

Using these data, the following values were obtained as the design EASL.

Table AP5.3.7 Design EASL by Alternative

Items		ALT-1	ALT-2	ALT-3	Remarks
Design Period (Year)	From	2013			
	To	2019	2022	2025	
Cumulative Traffic Volume (Million)	LV	8.235	12.970	18.412	
	HV	1.609	2.472	3.441	
ESAL (Million)	LV	0.030	0.047	0.066	
	HV	3.042	4.672	6.503	
Total ESAL (Million)		3.071	4.719	6.569	2 Direction
		1.735	2.666	3.712	1 Direction
Design ESAL (Million)		1.74	2.67	3.71	

Source: JICA Study Team

5) Design CBR and M_R

As described in Section 5.3.5, it is assumed that filling material for subgrade and embankment is brought from outside of the study area. And, the material of borrow pits is estimated as silty sand with gravel or sandy silt with gravel. The range of design CBR for this material will be expected about 5-10%. Therefore, design CBR for the Study was assumed to be 7.0. This value was used for whole section of the Study.

Using Design CBR, value of M_R was calculated by the following formula.

$$M_R = CBR \times 1{,}500 = 7 \times 1{,}500 = 10{,}500 \text{ (psi)}$$

6) Determination of Z_R, S_0, and ⊿PSI

Values of Z_R, S_0, and ⊿PSI were assumed at the standard values shown in AASHTO Design Guide as shown in Table AP5.3.8.

Table AP5.3.8 Values of Z_R, S_0, and ⊿PSI

Z_R:	- 0.674	(R = 75 %: typical value shown in AASHTO Design Guide)
S_0:	0.450	(typical value shown in AASHTO Design Guide)
⊿PSI:	1.9	(= 4.4 – 2.5: typical value shown in AASHTO Design Guide)

Source: Design Guide for Pavement Structure, AASHTO

7) Calculation of Required Structure Number (SN)

Using the formula and the values described above subsections, required SN for each alternative was calculated as shown in Table AP5.3.9.

Table AP5.3.9 Required SN by Alternative of NR-1

Items	ALT-1	ALT-2	ALT-3
Design ESAL (Million)	1.74	2.67	3.71
Design CBR	7		
Required SN	2.971	3.181	3.352

Source: JICA Study Team

8) Establishment of Pavement Structure for Each Alternative

To establish the pavement structure, the minimum thickness of each layer shall be fulfilled. These criteria are adopted from JRO standard with reference with AASHTO Design Guide.

These alternatives were selected to satisfy the required SN and also to satisfy the requirement for minimum thickness of each layer.

The structures of the alternatives are shown in Table AP5.3.10.

Table AP5.3.10 Alternatives of Pavement Structure for NR-1

Items		ALT-1	ALT-2	ALT-3
Required SN		2.971	3.181	3.352
Surface and Binder Course	Thickness	10 cm	10 cm	10 cm
	SN	1.654	1.654	1.654
Base Course	Thickness	15 cm	15 cm	20 cm
	SN	0.614	0.614	0.819
Subbase Course	Thickness	20 cm	26 cm	25 cm
	SN	0.724	0.942	0.906
Total	Thickness	45 cm	51 cm	55 cm
	SN	2.992	3.209	3.378

Source: JICA Study Team

9) Life Cycle Cost Analysis (LCC Analysis)

To verify the economic justification, life cycle costs (LCC) of Alternatives are compared. Prior to LCC analysis, maintenance scenario was assumed as shown in Table AP5.3.11. The period from 1st to 3rd year after construction was applied "No maintenance work", because the maintenance scenario exclude operation cost such as the electricity charges for lighting.

Table AP5.3.11 Maintenance Scenario

Period	Maintenance Work
1st – 3rd year after construction	No maintenance work
4th – End year of design period	Repair of pot holes etc: Cost is 1 % of new construction
Next year after design period	Overlay implemented: Thickness is 5cm.
Two years after design period	Repeat the cycle between 1st year and next year after design period above

Source: JICA Study Team

The result of the analysis is summarized in Table AP5.3.12. Cost index of which 1.0 was assumed overlay cost was applied to the cost comparison, and costs per square meter was compared at the analytical period of 20 years

LCCs of ALT-1 and ALT-3 are higher than that of ALT-2 by 4.683 % and by 0.326 %. Consequently, from economic viewpoint, ALT-2 is desirable among alternatives. And, it is recommended to adopt 10 years as design period.

Table AP5.3.12 Summary of LCC Analysis

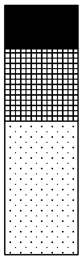
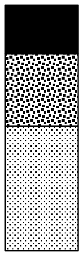
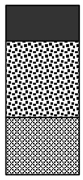
Items	Cost Index		
	ALT-1	ALT-2	ALT-3
Construction Cost	2.6826	2.7716	2.8473
Maintenance Cost	0.6690	0.4008	0.3291
Salvage Cost	0.2781	0.2873	0.2952
Total	3.6297	3.4597	3.4715
Ratio against ALT-1 (%)	100.000%	95.317%	95.643%

Source: JICA Study Team

10) Comparison with Adjacent Section

Comparison of pavement structure with adjacent section is shown in Table AP5.3.13. The total thickness of the proposed pavement is almost the same as JICA Section. And, the proposed pavement was evaluated by JRO Standard. Therefore, the proposed pavement structure is clarified to be appropriate.

Table AP5.3.13   Comparison of Pavement with Adjacent Section

Project		JICA B/D Section	Study Section	ADB Section
Cumulative ESAL		$2.18x10^{6}$	$2.67x10^{6}$	$2.0–3.0x10^{6*}$
Design CBR		7 (after replacement)	7	–
Pavement Structure				
Thickness (cm)	Surfce Course	9.0	10.0	7.5
	Base Course	15.0	15.0	16.0
	Subbase Course	28.0	26.0	12.0
	Total	52.0	51.0	35.5
Material	Surfce Course	AC	AC	DBST
	Base Course	Mechanically Stabilied	Crusher-run	Crushed Rock
	Subbase Course	Stabilized Sand	Granular Material	Gravel

*: 50% is used for Heavy Direction Ratio.

Source: Prepared by JICA Study Team

11) Motorbike Lane

In the view of cost minimizing, the pavement thickness on motorbike lane was modified and examined as follows, because ALEF of motorbike is small as it is possible to disregard it. Vehicles, however, pass through motorbike lane to stop in the roadside or to turn at intersection. On the other hand, great change of the pavement thickness causes the rise of cost and the error during construction due to complex of works.

Considering above mentions, modification of pavement thickness was conducted on the following conditions.

- Cumulative EASL of motorbike lane is assumed 20 percentage of the one of the carriageway.
- Total thickness is adjusted only by surface course, No change is other layers.
- Design period is applied 10 years as well as the one for vehicle lane.

According to the above conditions, pavement thickness for motorbike lane was modified as shown in Table AP5.3.14, and 6 cm in thickness of surface course was recommended for motorbike lane.

Table AP5.3.14 Modification of Pavement for Motorbike Lane

Design ESAL (Million)	Vehicle Lane	2.67
	Motorbike Lane	0.53
Design CBR		7
Required SN		2.457
Pavement Structure	Thickness	SN
Surface and Binder Course	6 cm	0.992
Base Course	15 cm	0.614
Subbase Course	26 cm	0.942
Total	47 cm	2.548

Source: JICA Study Team

(2) NR-11 Bypass

1) Required SN

Using future traffic demand on NR-11 bypass, the required SN for NR-11 bypass is calculated in the same procedure and same conditions as for NR-1 in the Study.

The result of the calculation is summarized in Table AP5.3.15.

Table AP5.3.15 Required SN of NR-11 Bypass

	From	To	Period
Design Period	2013	2022	10 years
	LV	HV	Total
Cumulative Traffic Volume (Million)	2.725	0.512	3.237
ESAL (Million)	0.010	0.967	0.977
	Vehicle	Motorbike	Remarks
Design ESAL	0.55	0.11	1-Direction
Required SN	2.471	1.892	

Source: JICA Study Team

2) Pavement Structure

According to the future traffic demand of NR-11 bypass in 2020, Number of the heavy vehicles pre day per direction was few 100 or less. Alternatives were established so that applying the modification of pavement thickness on motorbike lane as well as main road verify appropriate from an economical viewpoint.

Each Alternatives and the result of the estimation is summarized in Table AP5.3.16. Cost index of which 1.0 was assumed the cost of overlay with 5 cm in thickness was applied to the cost comparison as well as main road, and costs per cross section was compared.

Construction cost (initial cost) of ALT-b is higher than that of ALT-a by 8.05 %. Consequently, from economic viewpoint, ALT-a is recommended as the appropriate pavement structure for NR-11 bypass. Pavement structure of car lane and motorbike lane become the same.

Table AP5.3.16 Comparison with Alternatives of Pavement Structure for NR-11 Bypass

Items		ALT-a	ALT-b	
			Vehicle	MC
Required SN		2.471	2.471	1.892
Surface and Binder Course	Thickness	6 cm	8 cm	4 cm
	SN	0.992	1.323	0.661
Base Course	Thickness	19 cm	15 cm	15 cm
	SN	0.778	0.614	0.614
Subbase Course	Thickness	20 cm	18 cm	18 cm
	SN	0.724	0.652	0.652
Total	Thickness	45 cm	41 cm	37 cm
	SN	2.494	2.589	1.928
Width		9.5	6.5	3.0
Unit Cost Index		1.943	2.300	1.664
Total Cost Index		18.458	19.943	
Cost Raito (ALT-b/ALT-a)		1.0000	1.0805	

Source: JICA Study Team

(3) Minimum Thickness by Layer

Table AP.5.3.17 Minimum Thickness (AASHTO) (inches)

Traffic, ESAL	Asphalt Concrete	Aggregate Base
Less than 50,000	1.0 (or surface treatment)	4
50,001 – 150,000	2.0	4
150,001 – 500,000	2.5	4
500,001 – 2,000,000	3.0	6
2,000,001 – 7,000,000	3.5	6
Greater than 7,000,000	4.0	6

Source: Design Guide for Pavement Structure, AASHTO

Table AP.5.3.18 Class of Design Traffic Volume (JRO)

Class of Design Traffic Volume	Traffic Volume of Heavy Vehicles (Vehicle/day/direction)
L	Less than 100
A	100 – 249
B	250 – 999
C	1,000 – 2,999
D	3,000 or more

Source: Manual for Asphalt Pavement, JRO

Table AP.5.3.19 Minimum Thickness of Surface Course (JRO)

Class of Design Traffic Volume	Thickness (cm)
L, A	5
B	10 (5)*
C	15 (10)*
D	20 (15)*

Note: Thickness in ( ) can be used where the base course material is asphalt-stabilized.
Source: Manual for Asphalt Pavement, JRO

Table AP.5.3.20 Minimum Thickness of Base Course and Subbase Course (JRO)

Material/Construction Method	Minimum Thickness of Layer
Asphalt-stabilized	2 times of the maximum grain size and 5 cm
Other than above	3 times of the maximum grain size and 10 cm

Source: Manual for Asphalt Pavement, JRO

Table AP.5.3.21 Traffic of NR-1 by Alternative

Items	ALT-1	ALT-2	ALT-3
Cumulative ESAL	1.76 million	2.67 million	3.71 million
Heavy Vehicle (veh./day/lane)	409	463	518

Source: JICA Study Team.

(4) Calculation of Pavement Structure for NR-1

1) Calculation of Pavement Structure for NR-1 by AASHTO

Estimated SN is calculated by following formula in AASHTO Standard:

$$\text{Estimated SN} = T_1 \times SC_1 \times DF1 + T_2 \times SC_2 \times DF_2 + \cdots + T_i \times SC_i \times DF_i + \cdots + T_n \times SC_n \times DF_n$$

Where: $T_1, T_2, \cdots, T_i, \cdots, T_n$: Thickness of each layer (inch)

$SC_1, SC_2, \cdots, SC_i, \cdots, SC_n$: Structural coefficient of each layer

$DF_1, DF_2, \cdots, DF_i, \cdots, DF_n$: Drain Factor of each layer

Table AP.5.3.22 Structural Coefficient and Drain Factor of Each Layer

Layer	Structural Coefficient (per inch)	Drain Factor (per inch)
Surface Course (AC)	0.42	1.0
Base Course (Stabilized Gravel)	0.13 (CBR = 80)	0.8
Subbase Course (Crushed Stone)	0.115 (CBR = 30)	0.8

Source: Design Guide for Pavement Structure, AASHTO

Table AP.5.3.23 Establishment of Pavement Structure of NR-1 by Alternative

ALT-1	Target SN		2.971	Target SN - Estimated SN		-0.021
	Layers	Thickness (cm)	Thickness (inch)	Structural Coefficient	Drain Factor	Estimated SN
	Surface Course	4	1.575	0.420	1.0	0.661
	Binder Course	6	2.362	0.420	1.0	0.992
	Base Course	15	5.906	0.130	0.8	0.614
	Subbase Course	20	7.874	0.115	0.8	0.724
	Total	45	17.717			2.992
ALT-2	Binder Course		3.181	Target SN - Estimated SN		-0.028
	Layers	Thickness (cm)	Thickness (inch)	Structural Coefficient	Drain Factor	Estimated SN
	Surface Course	4	1.575	0.420	1.0	0.661
	Binder Course	6	2.362	0.420	1.0	0.992
	Base Course	15	5.906	0.130	0.8	0.614
	Subbase Course	26	10.236	0.115	0.8	0.942
	Total	51	20.079			3.209
ALT-3	Subbase Course		3.352	Target SN - Estimated SN		-0.026
	Layers	Thickness (cm)	Thickness (inch)	Structural Coefficient	Drain Factor	Estimated SN
	Surface Course	4	1.575	0.420	1.0	0.661
	Binder Course	6	2.362	0.420	1.0	0.992
	Base Course	20	7.874	0.130	0.8	0.819
	Subbase Course	25	9.843	0.115	0.8	0.906
	Total	55	21.654			3.378

Source: JICA Study Team.

Table AP.5.3.24 LCC Analysis

Alternatives		ALT-1		ALT-2		ALT-3	
Year	Discount Rate	Nominal	Discounted	Nominal	Discounted	Nominal	Discounted
0	1.0000	2.6826	2.6826	2.7716	2.7716	2.8473	2.8473
1	0.8929	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.7972	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.7118	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.6355	0.0268	0.0170	0.0277	0.0176	0.0285	0.0181
5	0.5674	0.0268	0.0152	0.0277	0.0157	0.0285	0.0162
6	0.5066	0.0268	0.0136	0.0277	0.0140	0.0285	0.0144
7	0.4523	0.0268	0.0121	0.0277	0.0125	0.0285	0.0129
8	0.4039	1.0000	0.4039	0.0277	0.0112	0.0285	0.0115
9	0.3606	0.0000	0.0000	0.0277	0.0100	0.0285	0.0103
10	0.3220	0.0000	0.0000	0.0277	0.0089	0.0285	0.0092
11	0.2875	0.0000	0.0000	1.0000	0.2875	0.0285	0.0082
12	0.2567	0.0268	0.0069	0.0000	0.0000	0.0285	0.0073
13	0.2292	0.0268	0.0061	0.0000	0.0000	0.0285	0.0065
14	0.2046	0.0268	0.0055	0.0000	0.0000	1.0000	0.2046
15	0.1827	1.0000	0.1827	0.0277	0.0051	0.0000	0.0000
16	0.1631	0.0000	0.0000	0.0277	0.0045	0.0000	0.0000
17	0.1456	0.0000	0.0000	0.0277	0.0040	0.0000	0.0000
18	0.1300	0.0000	0.0000	0.0277	0.0036	0.0285	0.0037
19	0.1161	0.0268	0.0031	0.0277	0.0032	0.0285	0.0033
20	0.1037	0.0268	0.0028	0.0277	0.0029	0.0285	0.0030
Salvage Value	0.1037	2.6826	0.2781	2.7716	0.2873	2.8473	0.2952
Total	1.0000		3.6297		3.4597		3.4715

Source: JICA Study Team.

2) Check the Selected Pavement Structure for NR-1 by JRO Standard

According to the JRO Standard, pavement structure is evaluated by the value of T'_A and H of total pavement thickness. T_A represents the pavement thickness required if the entire depth of the pavement were to be constructed of hot asphalt mixture, used for binder and surface courses.

Estimated SN is calculated by following formula in JRO Standard:

$$T'_A = a_1 \text{ x } T_1 + a_2 \text{ x } T_2 + \cdots a_i \text{ x } T_i + \cdots + a_n \text{ x } T_n$$

Where: $a_1, a_2, \cdots, a_i, \cdots, a_n$: Conversion coefficient of each layer

$T_1, T_2, \cdots, T_i, \cdots, T_n$: Thickness of each layer (cm)

Table AP.5.3.25 Target Value for T_A and Total Thickness H

Design CBR	Target Value (cm)									
	L Traffic		A Traffic		B Traffic		C Traffic		D Traffic	
	T_A	H	T_A	H	T_A	H	T_A	H	T_A	H
2	17	52	21	61	29	74	39	90	51	105
3	15	41	19	48	26	58	35	70	45	90
4	14	35	18	41	24	49	32	59	41	70
6	12	27	16	32	21	38	28	47	37	55
8	11	23	14	27	19	32	26	39	34	46
12	-	-	13	21	17	26	23	31	30	36
20	-	-	-	-	-	-	20	23	26	27

Source: Manual for Asphalt Pavement, JRO

Table AP.5.3.26 Conversion Coefficient of Each Layer

Layer	Conversion Coefficient (per cm)
Surface and Binder Course (AC)	1.00
Base Course (Stabilized Gravel)	0.35 (CBR = 80)
Subbase Course (Crushed Stone)	0.25 (CBR = 30)

Source: Manual for Asphalt Pavement, JRO

Based on traffic volume, ALT-2 was classified into "B Traffic". And, Design CBR of 7.0 was applied. Therefore, required T_A and H are 21 cm and 38 cm respectively.

Table AP.5.3.27 Evaluation of Selected Pavement Structure of NR-1 by RJO

Layers	Thickness (cm)	Conversion Coefficient	T_A (cm)
Surface Course	4.0	1.00	4.00
Binder Course	6.0	1.00	6.00
Base Course	15.0	0.35	5.25
Subbase Course	26.0	0.25	6.50
Total (A)	51.0	2.60	21.75
Target Value (B)	38.0		21.00
A-B	13.0		0.75

Source: JICA Study Team.

(5) Motorbike Lane on NR-1

Table AP.5.3.28 Evaluation of Motorbike Lane by AASHTO

Target SN		2.457	Target SN - Estimated SN		-0.091
Layers	Thickness		Structural Coefficient	Drain Factor	Estimated SN
	(cm)	(inch)			
Binder Course	6	2.362	0.420	1.0	0.992
Base Course	15	5.906	0.130	0.8	0.614
Subbase Course	26	10.236	0.115	0.8	0.942
Total	47				2.548

Source: JICA Study Team.

(6) National Road NR-11 Bypass

1) Calculation of Pavement Structure for NR-11 Bypass by AASHTO

Table AP.5.3.29 Traffic of NR-11 Bypass

Items	Vehicle
Cumulative ESAL	3.237 million
Heavy Vehicle (veh./day/lane)	96

Source: JICA Study Team.

Table AP.5.3.30 Establishment of Pavement Structure of NR-11 Bypass by Alternative

Alternative		Layers	Thickness (cm)	Thickness (inch)	Structural Coefficient	Drain Factor	Estimated SN
ALT-a		Target SN		2.471	Target SN - Estimated SN		-0.023
ALT-a		Surface Course	6	2.362	0.420	1.0	0.992
ALT-a		Base Course	19	7.480	0.130	0.8	0.778
ALT-a		Subbase Course	20	7.874	0.115	0.8	0.724
ALT-a		Total	45	17.717			2.494
ALT-b	Vehicle	Target SN		2.471	Target SN - Estimated SN		-0.118
ALT-b	Vehicle	Surface Course	8	3.150	0.420	1.0	1.323
ALT-b	Vehicle	Base Course	15	5.906	0.130	0.8	0.614
ALT-b	Vehicle	Subbase Course	18	7.087	0.115	0.8	0.652
ALT-b	Vehicle	Total	41	16.142			2.589
ALT-b	Motorbike	Target SN		1.892	Target SN - Estimated SN		-0.036
ALT-b	Motorbike	Surface Course	4	1.575	0.420	1.0	0.661
ALT-b	Motorbike	Base Course	15	5.906	0.130	0.8	0.614
ALT-b	Motorbike	Subbase Course	18	7.087	0.115	0.8	0.652
ALT-b	Motorbike	Total	37	14.567			1.928

Source: JICA Study Team.

2) Check the Selected Pavement Structure for NR-11 Bypass by JRO Standard

Based on traffic volume, ALT-a was classified into “L Traffic”. And, Design CBR of 7.0 was applied. Therefore, required T_A and H are 12 cm and 27 cm respectively.

Table AP.5.3.31 Evaluation of Selected Pavement Structure of NR-11 Bypass by RJO

Layers	Thickness (cm)	Conversion Coefficient	T_A (cm)
Surface Course	6.0	1.00	6.00
Base Course	19.0	0.35	6.65
Subbase Course	20.0	0.25	5.00
Total (A)	45.0		17.65
Target Value (B)	27.0		12.00
A-B	18.0		5.65

Source: JICA Study Team.

AP 5.3.3 Road Safety and Road Management Facilities

(1) Safety Measure on Bridge

The necessity of countermeasures against the traffic accident on the bridge should rise in consideration of traffic characteristics in Cambodia as described in Section 5.1.3. Though there are various types of devices as countermeasures to separate car lane and motorbike lane such as rubber posts, delineator and so forth, the devices should be selected considering the following points:

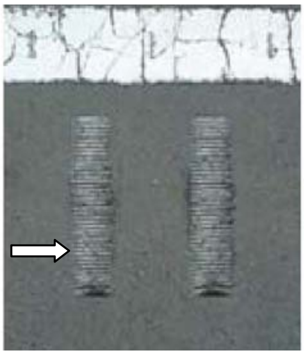
- No additional space for the installation
- Not breakable even if the heavy vehicle steps on
- Prerequisite to install traffic signs and ordinary road markings

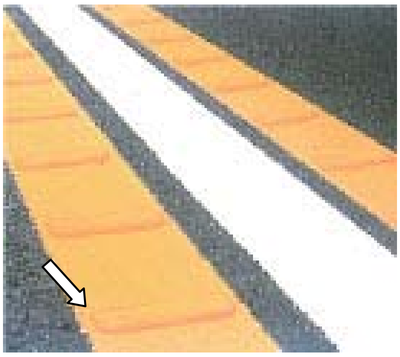
Major devices that meet the above requirement and applied in Japan are introduced as follows.

- Road studs with reflector (normal size: size W150xB130xH20~30mm)
- Mounted pavement strips (size H10~30mm)
- Ramble strips (size W350xB80xH9~12mm in 150mm Intervals)
- Road markings with ribs (size H7mm)
- Centralized road markings (size W300~450mm)
- Color pavement (size H10mm)

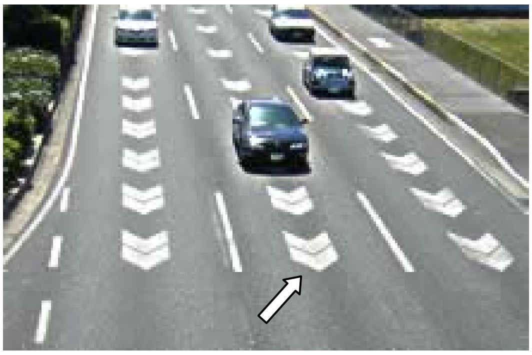
A. Road studs with reflector

B. Mounted pavement strips





C. Ramble Strips **D. Details of Ramble Strips** **E. Road markings with ribs**



F. Centralized road markings **G. Color pavement**

Source:
A. http://www.azuma-syokai.co.jp/safty/index.htm
B. http://www.azuma-syokai.co.jp/safty/goods-m.htm
C. http://www.e-nexco.co.jp/service/challenge/traffic.shtml
D. http://www.hokuhoku.ne.jp/rmec/15pdf/22-24.pdf
E. http://www.cbr.mlit.go.jp/mie/q-a/road/road22.html
F. http://www.kotuanzenyanen.com/sisetu/romen/index_romen.html
G. http://www.tottori-mlit.go.jp/koge/construct/anzentaisaku/otiori-wakasa.html

Photograph AP5.3.1 Sample of Safety Devices

Road studs with reflector have the possibility that the motorbike slips in the section with the steep vertical grade, because it is made of the metal. Mounted pavement strips might disturb smooth drain. As for road markings with ribs, the abrasion of the rib is assumed so fast. On the other hand, the abrasion resistance of the ramble strips is assumed to be higher than the road markings with ribs. Centralized road markings are useful to draw motorbike driver's attention, and there is an effect of concentration to the center of the lane in visual. There are some types of color pavement, and one of them has the slipping prevention function.

Considering the above features of the devices and the traffic characteristics in Cambodia, it is proposed to compound the following devices.

- Ramble strips (size W350xB80xH9~12mm in 150mm Intervals)
- Centralized road markings (size W300~450mm)
- Color pavement (size H10mm)

Moreover, the effect will increase, if the road studs on the curb are installed.

Source: http://www.koutsukikaku.co.jp/eigyo2.html

Photograph AP5.3.2 Sample of Road Studs on the Curb

(2) Traffic Signs

The traffic sign is one of the traffic control devices, which is used to regulate, warn or guide road users. Traffic signs are stipulated in Cambodian Standard and shall be installed to satisfy the requirements.

1) Regulatory and Warning Signs

Regulatory signs inform road users of traffic rules and regulations and indicate the applicability of legal requirements that would not otherwise be apparent.

Warning signs are used when it is deemed necessary to warn traffic of existing or potentially hazardous condition on or adjacent to a road.

Principal regulatory and warning signs are planned to install at the following locations in the Study:

- Horizontally sharp curve (R < 500 m)
- Intersection and toll plaza

2) Guide Signs

Guide signs are to convey to drivers information such as destination and distance, service facilities and route confirmation. These signs play an important role in informing drivers in advance of correct traffic lane for marking an exit or entry at merging/diverging points and roadside facilities.

Principle guide signs are planned to install at major intersections and toll plaza in the Study.

(3) Road Markings

Road markings include all traffic lines, symbols, words and object marks. Road markings are particularly important to help in regulating traffic, warning or guiding road users. Road markings, like other traffic control devices, should be uniform in design, position and application so that they may be recognized and understood immediately by all road users.

Cambodian standard of road markings are not established. In reality, a foreign standard has been applied in each project. Therefore, Japanese Standard is proposed to apply for this project, because it is introduced at “Safety Measure on Bridge”. Road markings shall be installed to satisfy the requirements. And, the installation plan should be consulted with MPWT as the responsible authority during the detailed design stage.

Principal road markings will be painted on the pavement and be consisted of the following type in the Study:

- Centerline
- Lane markings at the boundary of a car lane and a motorbike lane
- Road edge
- Pedestrian crossing

Other types of road markings should be considered in the detailed design stage depending on the actual site condition.

(4) Kilometer Posts

Kilometer posts are to function as informing road users as well as to locate and orient them. Besides, it is useful for maintenance because the location of repair work become clear.

Kilometer posts are planned to install at 1 km interval.

(5) Guard Posts

Guard posts are to function as redirecting errant vehicles away from the roadside hazard and decelerating errant vehicle to a stop. Guard posts are delineated in term of geometry and location of roadside features.

Guard posts are planned to set up at the following locations in the Study:

- High embankment section (H > 4.0 m)
- Horizontally sharp curve (R < 500 m)
- Bridge and culvert approaches

(6) Road Lightings

Since there are comparatively, many objects that become troubles on the road with low reflectivity, the discovery probability of such obstacles by the road lightings is generally higher than by the car lightings. In addition, the road lightings have an excellent effect such as the expansion of driver’s sight, the improvement of an unobstructed driver’s view and the guidance of driver’s eyes. The road lightings are planned at the following locations in the Study to maintain smooth and safe traffic at nigh:

- Major intersections and toll plaza
- Bridge and its approach

(7) Road Studs

As discussed above, road studs have the possibility that the motorbike will easily slip in the section with the steep vertical grade. However, a high effect can be expected for the 4-wheel vehicles. Road studs are particularly important to help in regulating traffic, warning or guiding road users like road markings. Road studs with reflector have a function of guidance of driver’s eyes.

The road studs with reflector are planned on the centerline in every 25-meter in this Study.

AP 5.5 Selection of Bridge Type

AP 5.5.1 Evaluation of Six bridge alternatives by AHP

Two Bridge types be selected as the candidates of the main bridge for the Project. Following two procedures are carried out for the selection of the optimal bridge type.

(1) Process-1

Optimal bridge type should be selected from the engineering point of view referring to evaluation criteria.

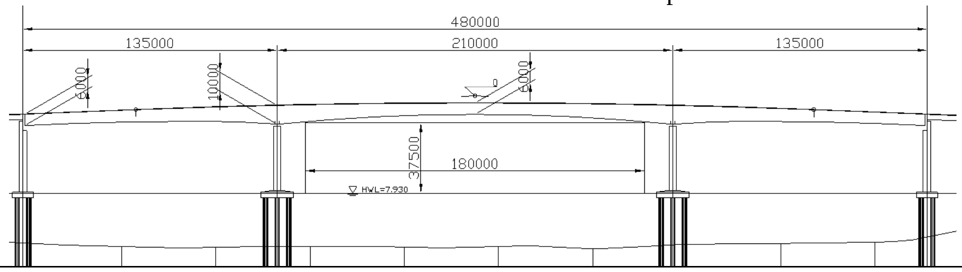
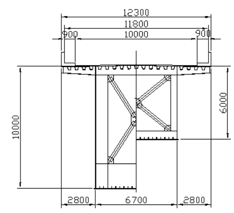
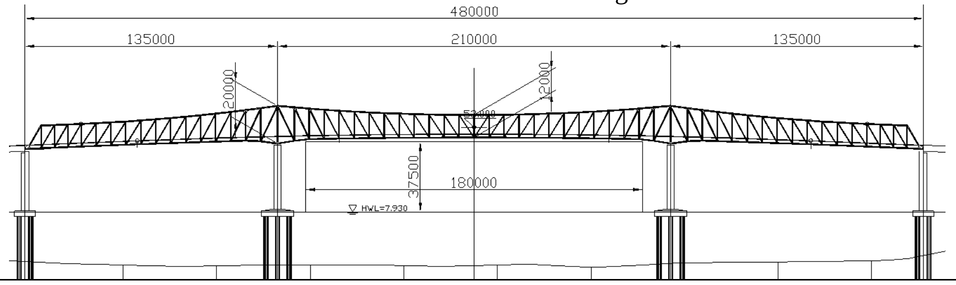
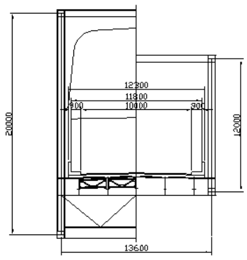
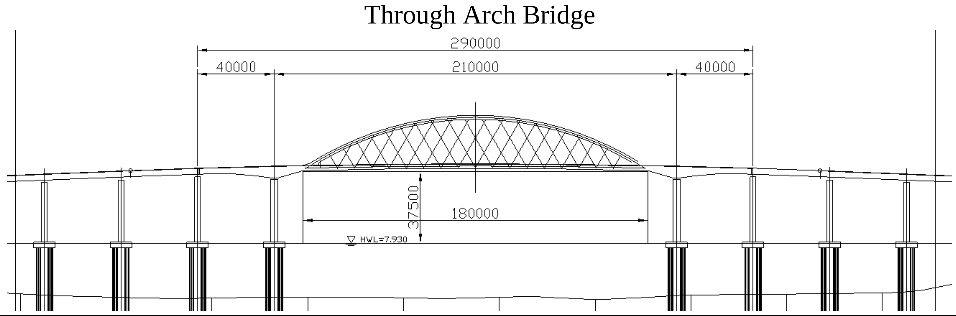
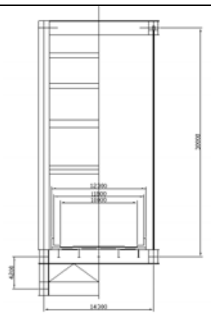
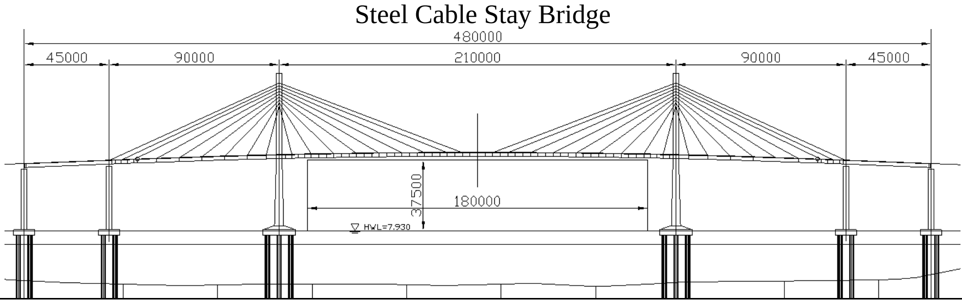
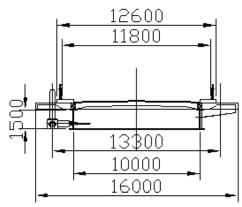
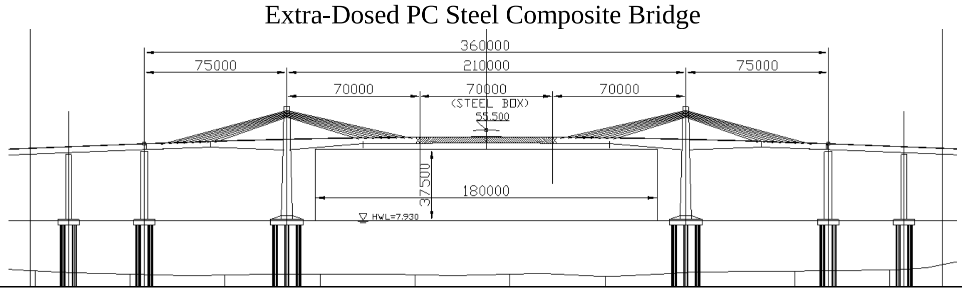
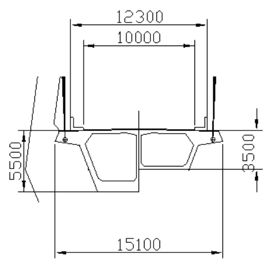
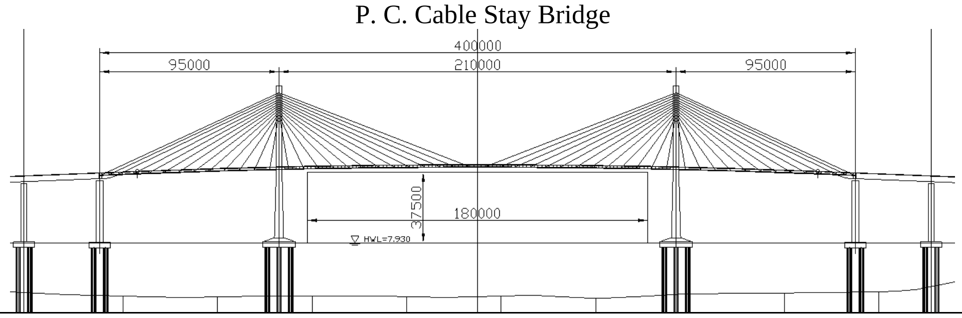
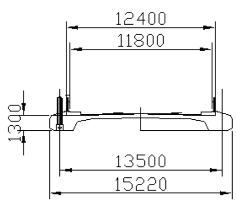
(2) Process-2

Result of engineering judgment should be checked utilizing the AHP (the Analytic Hierarchy Process)

1) Evaluation criteria

Evaluation criteria are as follows.

1. Construction Cost:
2. Property of structure
    a. Contribution to Cambodian Economy, opportunities of working and technical transfer.
    b. Past record, technical assurance and stability and suitability to the natural condition
3. Construction method
    a. Construction term
    b. Safety for construction
4 Maintenance
5 Aesthetic point of view

	ELEVATION	CROSS SECTION
Type 1	Continuous Steel Box Girder with Orthotropic Deck 	
Type 2	Continuous Steel Truss Bridge 	
Type 3	Through Arch Bridge 	
Type 4	Steel Cable Stay Bridge 	
Type 5	Extra-Dosed PC Steel Composite Bridge 	
Type 6	P. C. Cable Stay Bridge 	

2) Process-1

Construction cost should have first priority among items in the criteria. Both Cable Stayed Bridges, i.e., Type-4 and Type-6, are most reasonable cost rather than others. Cost of Cable Stayed Bridges are twenty (20) percent lower than the cost of steel bridge alternatives of Type1, Type2 and Type-3 and fifteen (15) percent lower than Composite Extra-Dosed bridge (Type-5).. As far as concern for the cost, Type-4 or Type-6 may be selected.

One of contribution to Cambodian economy, opportunities of working and technical transfer may use material produced in Cambodia, fabricate structures in the site and more Cambodian engineers are involved in the work. That means concrete structures would be suitable rather than steel structures because aggregates for concrete are typical material to be produced in Cambodia. For this point of view, Type-5 and Type-6 bridges may be favorable.

These six type bridges have safely constructed in the world and the bridge for the Project is within past record of dimension. However, wind induced vibration must be considered for lightweight and sensitive structures. Cable Stayed bride, especially Type-4, has sensitive property to wind action. Therefore wind tunnel tests must be performed to confirm the wind stability before Detailed Design.Type-6 bridge is also necessary to be carried out wind tunnel test. But Actual example similar to the bridge indicate that fatal behavior such as flatter and galloping will not occur and if wind vortex oscillation occur, aerodynamic countermeasure will be easily generated through the wind tunnel examination.

From Type-1 to Type-3 and Type-5 will be constructed in a shorter period if suitable construction yard will be prepared to assemble the bridge because of application of the lifting method that enable rapid construction. It seems difficult to prepare it near the site along the Mekong River.

Cable Stayed Bridge, Type-4 and Type-6, will be constructed adopting balanced-cantilever method. Its cyclic procedure of construction is recognized rational and safety.

Maintenance will be needed for every type of bridges but bridges made of concrete are able to minimize its cost.

Aesthetic aspect of the bridge should be important issue to select bridge type. Cable Stayed Bridge is generally recognized elegant and symbolic structure of the area and can become the landmark there.

Accordingly, Cable Stayed Bridge, Type-4 and Type-6, should be selected for the candidates of the bridge for the Project.

3) Process-2

Check to result of Process-1 should be confirmed utilizing AHP (Analytic Hierarchy Process) method. Results of AHP are as follows.

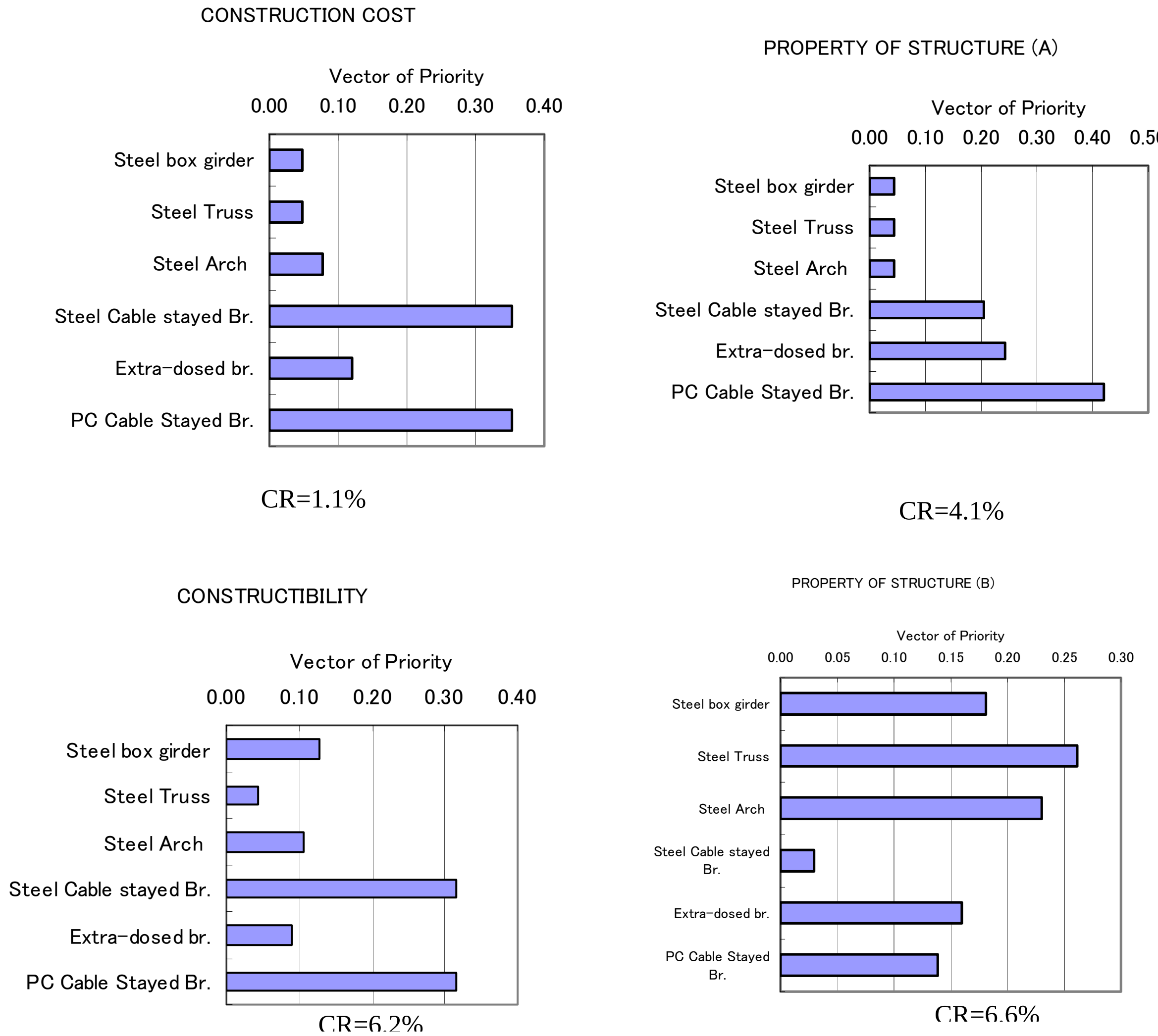
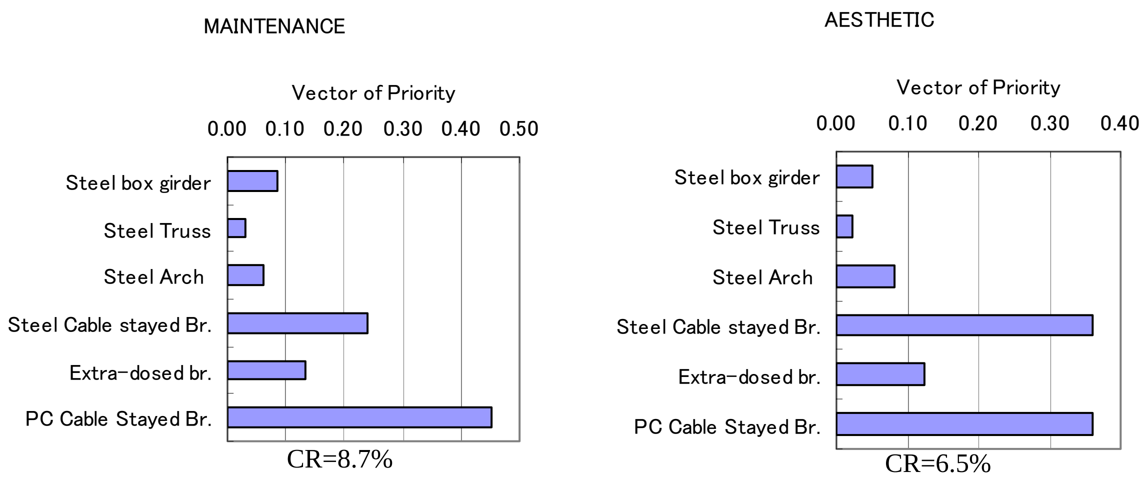


Figure AP5.5.2 Results of AHP(1)



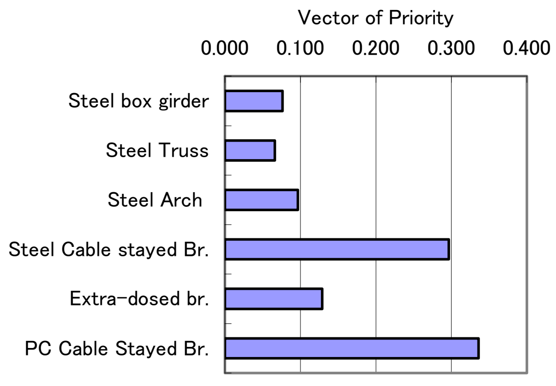


Figure AP5.5.3 Results of AHP (2)

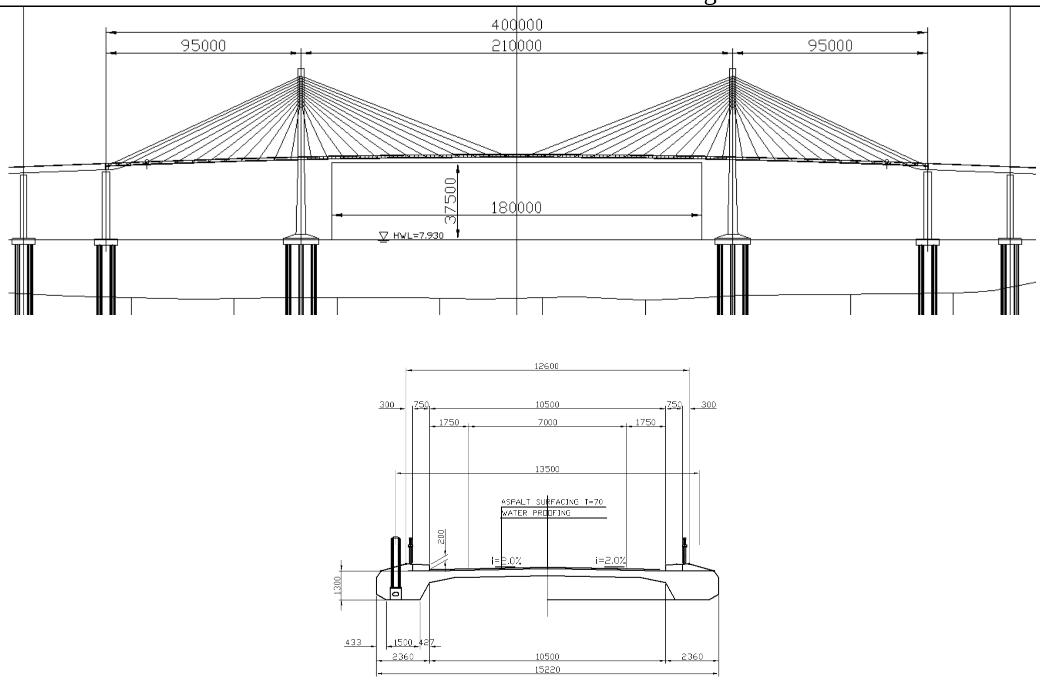
Results of evaluation by AHP are same as the results of the engineering judgment through Pprocess-1. Therefore Cable Stayed Bridges i.e., Type-4 and Type-6, are selected for the next evaluation stage.

AP 5.5.2 Comparison of Steel Girder and Concrete Girder for Cable Stay Bridge

There are two type of main girder, concrete girder and steel girder are commonly utilized for the Cable Stay Bridge. Comparison to select optimal type of cable stay bridge is carried out and result is summarized in Figure AP5.5.4 and Table AP5.5.1

Profile and Cross Section of Bridge

ALTERNATIVE 1 (Concrete Girder)



ALTERNATIVE 2 (Steel Girder)

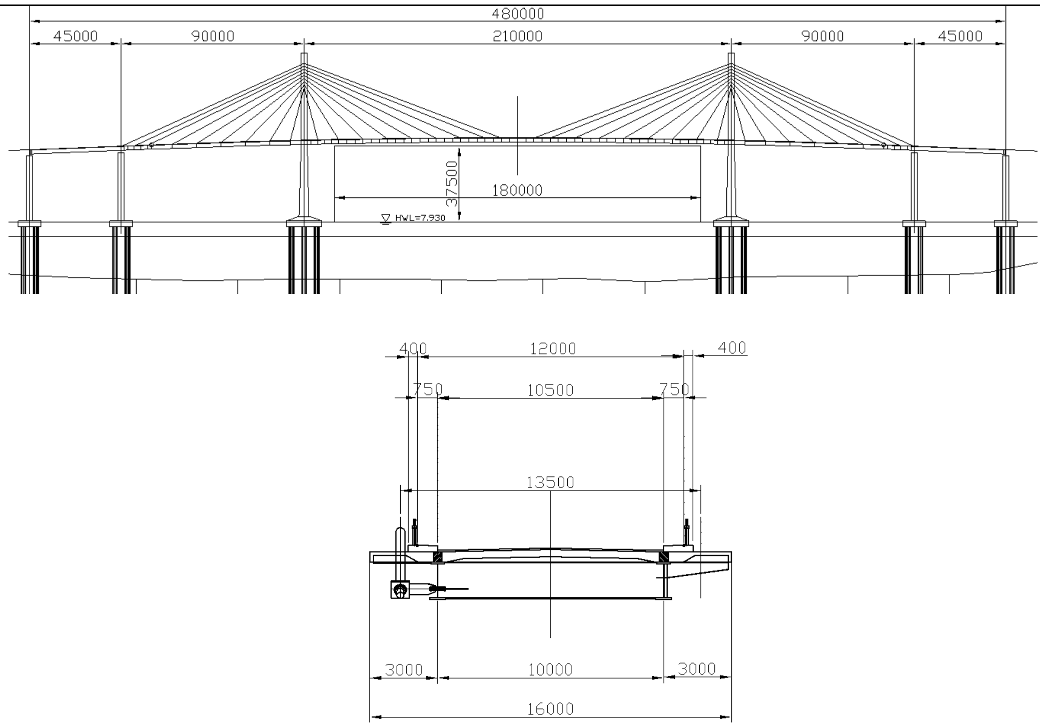


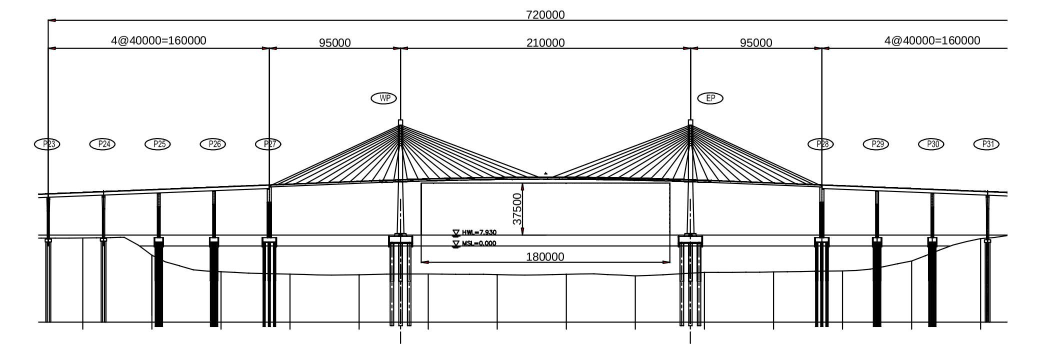
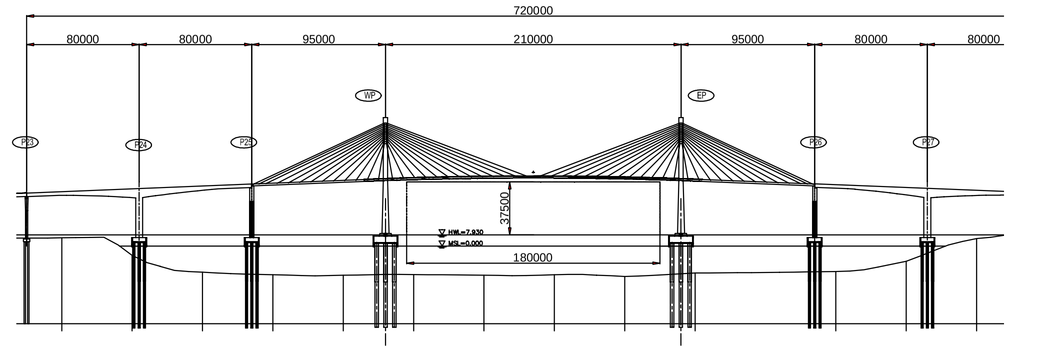
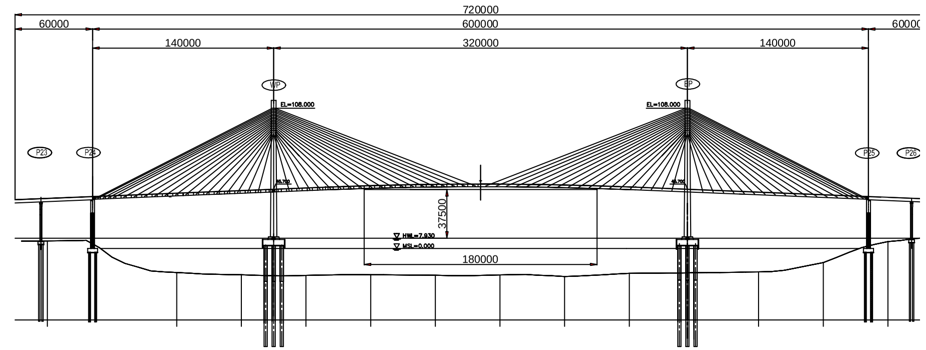
Figure AP5.5.4 Comparison of Cable Stayed Bridges

Table AP5.5.1 Comparison of Cable Stayed Bridges

<table>
<tr><td></td><td colspan="10">DESCRIPTION</td></tr>
<tr><td rowspan="16">ALTERNATIVE 1 (Concrete Girder)</td><td rowspan="10">COST</td><td colspan="8">Quantities of Main Br.</td><td>Cost</td></tr>
<tr><td rowspan="3">Girder</td><td>Concrete</td><td>m^3</td><td>4,868</td><td rowspan="3">Pylon</td><td>Concrete</td><td>m^3</td><td>2,121</td><td rowspan="4">$1,521 \times 10^6$(JPY)
【13.8(USD)】</td></tr>
<tr><td>Rebar</td><td>t</td><td>874</td><td>Rebar</td><td>t</td><td>728</td></tr>
<tr><td>PC-tendon</td><td>t</td><td>605</td><td>steel</td><td>t</td><td>104</td></tr>
<tr><td colspan="2">Stay cable</td><td>t</td><td>240</td><td colspan="4"></td></tr>
<tr><td colspan="8">Foundation</td><td rowspan="4">$1,419 \times 10^6$(JPY)
【12.9(USD)】</td></tr>
<tr><td rowspan="3">Pile cap</td><td>Concrete</td><td>m^3</td><td></td><td colspan="4">Type : Cast on place Concrete Pile</td></tr>
<tr><td>Rebar</td><td>t</td><td></td><td colspan="2">Diameter x Length</td><td>m</td><td>2.5 x 60m</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Number of Pile</td><td>nr</td><td></td></tr>
<tr><td colspan="9">Total $1,521 \times 10^6 + 1,419 \times 10^6 = 2,940 \times 10^6$(JPY) 【$26.7 \times 10^6$(USD)】</td></tr>
<tr><td rowspan="2">PROPERTY OF STRUCTURE</td><td colspan="9">Aggregates for concrete are procured in Cambodia. Other materials, such as cement, rebar, PC-tendon, steel plate, stay cables, shall be imported. Girder will be constructed by cast in place concrete so that opportunity for local labor to participate the project and technical transfer will large comparing to Alternative-2</td></tr>
<tr><td colspan="9">This type of bridge may have good aerodynamic stability because OHSHIBA Bridge, similar type of bridge, constructed in Japan in 1997, has excellent aerodynamic stability. However, wind tunnel test shall be carried out for the confirmation at the time of detailed design</td></tr>
<tr><td>CONST-RUCTION</td><td colspan="9">After the completion of Pylon, balanced cantilever method will be applied for construction of main girder. Segment of girder is constructed by cast in situ concrete works to both directions from Pylon. It is needed longer construction term than Alternatibe-2. Length of each segment is 4m and construction cycle of the segment is six (6) days.</td></tr>
<tr><td>MAINTENANCE</td><td colspan="9">Concrete Cable Stayed Bridge may needs least maintenance work within tens years after completion except ancillary facilities.</td></tr>
<tr><td>AESTHETICS</td><td colspan="9">Slenderness and simplicity of main girder show elegant feature than Alternative 2. This type of bridge is recommended from the aesthetic point of view.</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td rowspan="15">ALTERNATIVE 2 (Steel Girder)</td><td rowspan="10">COST</td><td colspan="8">Quantities of Main Br.</td><td>Cost</td></tr>
<tr><td rowspan="3">Girder and Slab</td><td>Concrete</td><td>m^3</td><td>2,822</td><td rowspan="3">Pylon</td><td>Concret e</td><td>m^3</td><td>2,121</td><td rowspan="4">$1,724 \times 10^6$(JPY)
【15.7(USD)】</td></tr>
<tr><td>Rebar</td><td>t</td><td>865</td><td>Rebar</td><td>t</td><td>636</td></tr>
<tr><td>Steel</td><td>t</td><td>1,643</td><td>Steel</td><td>t</td><td>106</td></tr>
<tr><td colspan="2">Stay cable</td><td>t</td><td>167</td><td colspan="4"></td></tr>
<tr><td colspan="8">Foundation</td><td rowspan="4">$1,273 \times 10^6$(JPY)
【11.6(USD)】</td></tr>
<tr><td rowspan="3">Pile cap</td><td>Concrete</td><td>m^3</td><td></td><td colspan="4">Type : Cast on place Concrete Pile</td></tr>
<tr><td>Rebar</td><td>t</td><td></td><td colspan="2">Diameter x Length</td><td>m</td><td>2.5 x 60m</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Number of Pile</td><td>nr</td><td></td></tr>
<tr><td colspan="9">Total $1,724 \times 10^6 + 1,273 \times 10^6 = 2,997 \times 10^6$(JPY) 【$27.2 \times 10^6$(USD)】</td></tr>
<tr><td rowspan="2">PROPERTY OF STRUCTURE</td><td colspan="9">Steel-girder will be fabricated in Japan and/or in third countries and transported to the construction site. Girder is erected by election girder or cable lifting method. Deck slab will be Pre-cast concrete.</td></tr>
<tr><td colspan="9">Wind tunnel test shall be carried out and confirmed its aerodynamic stability.</td></tr>
<tr><td>CONST-RUCTION</td><td colspan="9">Balanced Cantilever Method will be applied for the construction of main girder. Length of steel-girder segment will be 12 meters and girders and precast-concrete slabs are erected by traveler crane on the deck. Cycle time for the erection of each segment will be 12 days and total construction term will be shorter than Alternative 1.</td></tr>
<tr><td>MAINTENANCE</td><td colspan="9">In case normal painting applied, repainting will be required after ten or fifteen years from the time bridge is opened to traffic. If painting with long-term durability such as Fluorocarbon Resin Coating is used, term for the repainting will be more than twenty (20) years.</td></tr>
<tr><td>AESTHETICS</td><td colspan="9">Girder height is higher and structure of girder is complicated than Alternative 1. It will cause slightly dull image. Aesthetic image will be controlled by color painting to the girder and be able to harmonize to the circumstance and nature.</td></tr>
</table>

The concrete cable stay bridge is recommended for the Second Mekong Bridge based on the results of study mentioned above.

AP 5.5.3 Study of Span Length for Cable Stay Bridge

	Profile	Description
Case1 Center Span 210m Side Span 40m		1. Note Minimum requirement of the navigation width 180m are kept and approach bridge with span length 40m is constructed in the river. Number of pier in the river is 8 and high possibility of the collision of local ship into the piers is noticed. 2. Construction Cost Construction cost of bridge in the river (720m) is 26.9 mill US$ Total Bridge Construction cost 60.0 mill US$ 3. Recommendation Considering the high risk of the waterway accident, case 1 shall be avoided.
Case2 Center Span 210m Side Span 80m		1. Note Minimum requirement of the navigation width 180m are kept and approach bridge with span length 80m is constructed in the river. Number of pier in the river is 4 and navigation width for the local ship is less than that of Kizuna bridge. 2. Construction Cost Construction cost of bridge in the river (720m) is 31.4 mill US$ Total Bridge Construction cost 64.5 mill US$ 3. Recommendation Risk of the waterway accident is higher than Kizuna bridge, and case 2 is not recommended.
Case3 Center Span 320m Side Span 140m		1. Note Bridge with center span length 320m and approach span length 140m is constructed in the river. Number of pier in the river is 2 and possibility of the collision of local ship into the piers is minimized. 2. Construction Cost Construction cost of bridge in the river (720m) is 34.2 mill US$ Total Bridge Construction cost 67.4 mill US$ 3. Recommendation Considering the safety for the local ship, case 3 is recommended.

AP 5.5.4 A Letter from MPWT to the Study Team

KINGDOM OF CAMBODIA
Nation Religion King

Ministry of Public Works
and Transport

No. 1834 MPWT/MBSC

Date 07 OCT 2005

To: JICA Study Team for the Construction of the Second Mekong Bridge

Subject: Alternative Type of Bridge for Neak Leoung Bridge.

As discussed in the steering committee meeting for the Construction of the Neak Leoung Bridge which held at Ministry of Public Works and Transport of Cambodia on September 20, 2005, I recommended the horizontal navigation clearance of the main-span of the bridge shall be wider than the alternatives proposed by the Study Team. I do not deny that the future traffic demand of the international cargos which navigate under the bridge is not clear, however the alternatives shown by the study team has several defect as follows;

1. Based on the Article 9, Freedom of Navigation in the MRC Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin 1995. The Mekong River shall be kept free from obstruction, measure, conduct and actions that might directly or indirectly impair navigability, interfere with this right or permanently make it more difficult. The infrastructure constructed in the river shall be designed to minimize the disturbance to the river traffic.

2. Majority of the vessels which are used for the Mekong River haulage are regional vessels and the piers out side of the main-span can be hazardous for the regional vessels. Several collision accidents occurred between the local ship and the pier of KIZUNA bridge in recent years shall be noted.

The workers engaged in inland water transportation business are important stake holders for the Neak Leoung Bridge Construction Project and I believe that the safety of the peoples shall be taken into considered for the design of the bridge as much as possible. I would like to recommend to choose a bridge alternative which has minimum number of the piers in the Mekong River.

H.E. Mr. Tram Iv Tek
Secretary of State, Ministry of Public Works and Transport
Chairman of the Steering Committee of the Second Mekong Bridge Construction Project
106, Norodom Boulevard
Phnom Penh, Cambodia

Norodom Boulevard
Phnom Penh

Tel: (855) 23 430595
Fax: (855) 23 723515

AP 5.5.5 A Letter from MRC to CMRC (Carbon Copy to MPWT)

Mekong River Commission

P.O. Box 6101, 184 Fa Ngoum Road, Unit 18,
Ban Sithane Neua, Sikhottabong District, Vientiane 01000, Lao PDR
Telephone: (856-21) 263 263 Facsimile: (856-21) 263 264

10th Anniversary

No. L0884/05 Vientiane, 5 October 2005

Your Excellency,

<u>Subject</u>: **Feasibility Study for the Construction of the Neak Leoung Bridge**

On September 20, 2005, the Stakeholder Meeting 3-2 for the Construction of the Neak Leoung Bridge was held in Phnom Penh. One of the matters to be discussed was the horizontal clearance between the bridge piers. Representatives of the Mekong River Commission Secretariat attended this important Meeting.

On this occasion, H.E. Mr. Tram Iv Tek, Secretary of State of the Ministry of Public Works and Transport, requested the Mekong River Commission Secretariat to give technical advice regarding the navigation clearance. Because the Pacific Consultants International, co-responsible for the feasibility study, are gathering advice and recommendations before moving into the final stage of the study, the Ministry of Public Works and Transport asked MRCS to have a reply ready by the beginning of October 2005.

We are honored to be able to assist the Cambodian Government in this matter. In view of the limited time available however, we are not able to carry out in-depth technical investigations. Yet, we would like to forward some technical considerations which we hope can assist you in making your final decision.

In general we would recommend to choose the second of the three options, namely the cable stayed bridge (L320) with a horizontal clearance of 300m between the piers. The rationale for this is set out in the following considerations:

/...

H.E. Mr. Hou Taing Eng
Alternate Member of MRC Joint Committee for Cambodia
Secretary-General
Cambodia National Mekong Committee
23 Mao Tse Toung Road
Phnom Penh, Cambodia

Cc: **H.E. Mr. Tram Iv Tek**
Secretary of State, Ministry of Public Works and Transport
Vice-Chairman of Cambodia National Mekong Committee and
Alternate Member of the MRC Council for Cambodia
106, Norodom Boulevard
Phnom Penh, Cambodia (fax 023 724713 and 023 427 802)

1. Article 9, Freedom of Navigation in the MRC Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin (1995) states that " ... *The Mekong River shall be kept free from obstructions, measures, conduct and actions that might directly or indirectly impair navigability, interfere with this right or permanently make it more difficult.* " Although the rule is not quantified, it is clear that permanent structures should be planned in such a way that navigability is not impaired. In this respect, the infrastructure design has to be optimally chosen to cause least disturbances to its waters, and water related resources and activities,

2. In 1994, MRC has conducted a Study on the My Thuan Bridge, over the Mekong River in Viet Nam, and after consultations between the Governments of Cambodia and Viet Nam, guided by working groups and consultants, the plans were made. The design was concluded to have a vertical clearance of 37,5m and horizontal clearance of at least 300m. These clearances have left an important opportunity for future shipping not only within Viet Nam but also for shipping bound for Cambodia. Rationally speaking, these opportunities should be continued for as far as maritime accessibility extends, including the Mekong River stretch at the selected site of the Neak Leoung bridge,

3. Safety aspects: In Option 2 (L320) two-way shipping would be possible (one sea-going ship and one barge) between the main piers. Moreover, this option would imply an important clearance for country craft and barges outside the main piers. In Option 1 on the other hand, the passage clearance between the smaller (and more numerous) piers can be hazardous for local traffic using the passage way between the smaller piers,

4. The river is used for regional carriage of dangerous and hazardous cargo. Safety thresholds have to be increased for river haulage of such cargo as more clearance is required,

5. The Mekong River has nautical particularities such as very high currents and morphological changes which make navigation more challenging than most other rivers in the world,

6. The World Bank is currently investigating the investment of 150 mio USD to develop a new access channel from the sea into the Bassac River – to also benefit the ports on the Mekong river system in Cambodia.

7. The reference ship design of DWT 5,000 is valid for 15-20 years. The long term prospects could easily change. (40 years ago, the accessibility to the Mississippi river was only 3.5m deep. Now the Least Available Depth is more than 14m)

8. The standards that have been used in the report have to be cross-checked with other international standards. According to the Permanent International Association of Navigational Congresses (PIANC), the length over all (LOA) of a 5000 DWT vessel is 108 m. The Bridge Protection Planning Guidelines of the American Association of State Highway and Transportation Officials (AASHTO) state the following: *Bridges with main spans, S, less than 2 or 3 times the design vessel length, LOA, are particularly vulnerable to vessel collision.*

9. Hydraulic and morphological impacts. The option 1 (180m) – bridge design plans for 8 piers in the water – of which the two main set of piers have a diameter of 30 m.

   Back water effect: rough calculations have shown that the back water effect (or head loss) in option 1 can mount up to 3 - 4 cm, for well designed piers. Less favorable design can double these values.

../...

Morphological and scouring impacts: there will be some erosion in the bridge opening due to increased velocities and scouring around the foundations. The extent of this will depend on how much the river is constricted by the bridge, and the sedimentation/erosion effects can easily be modeled. In any case, Option 2 has only 2 piers which significantly reduces these impacts.

Your Excellency, please allow me to add a further point for consideration by the decision-makers: during the stakeholder meeting, one participant asked why the bridge carriage way only consists of one car lane for each direction even though the bridge is a link of a major regional highway, connecting Cambodia, Thailand and Viet Nam. The consultant replied that, if road traffic picks up at a rate higher than predicted, for example 30 years from now, another bridge can be constructed next to it provide an additional lane. Unfortunately, such an option cannot be provided for horizontal clearance of the bridge in case shipping to and from Cambodia increases more significantly than predicted: the horizontal width can never be changed. The decision of the Cambodian Government would therefore also need to take into account future growth potential beyond the medium term transportation requirements.

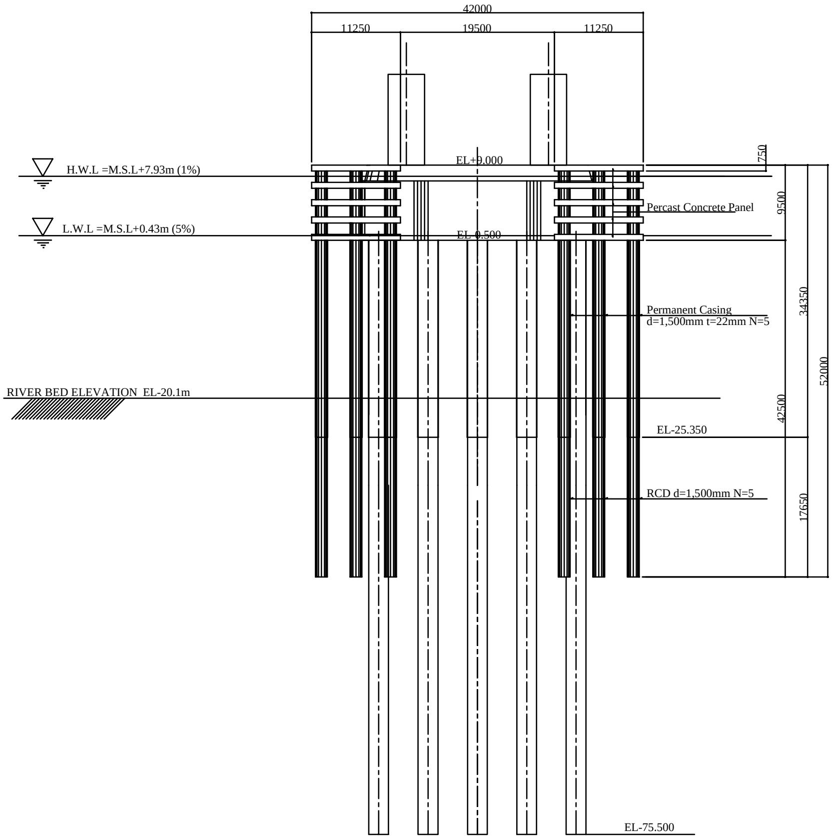
Your Excellency, we hope to have provided you with some valid arguments for the decision-makers and stand ready to provide further advice if required.

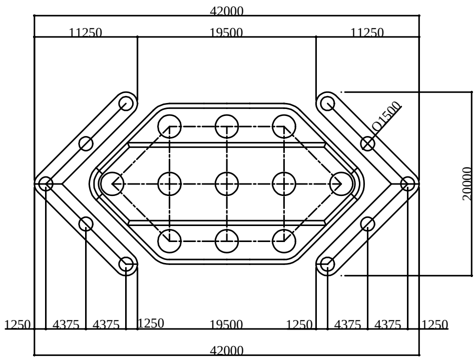
Please accept the renewed assurances of my highest consideration.

../..

Dr Olivier Cogels
Chief Executive Officer

AP 5.5.6 Protection for Foundation in the River





APPENDIX 6

CONSTRUCTION, OPERATION AND MAINTENACE OF THE PROJECT

APPENDIX 6 CONSTRUCTION, OPERATION AND MAINTENANCE OF THE PROJECT

AP6.3 Operation and Maintenance System of the Project

AP6.3.1 Current Situation of Road/Bridge Operation and Maintenance System

Table AP6.3.1 Details of Equipment of RCC

No.	Type	Team 1	Team 2	Team 3	Tem 4	Commune Team	PWT Dep.	Stone Crusher Team	Total
1	Bulldozer	1	1	1	1				4
2	Excavator	1	1						2
3	Motor grader	1	1	1	1				4
4	Wheel loader	1	1	1	1			2	6
5	Vibration roller	1	1	1	1				4
6	Macadam roller	1	1						2
7	Dump truck	3	3	3	3	2			14
8	Water tanker	1	1	1	1				4
9	Fuel tanker	1	1	1	1				4
10	Water pump	1	1	1	1				4
11	Pickup	1	1	1	1		5		9
12	Station wagon	1	1	1	1	1			5
13	Movable crusher							1	1
14	Dozer shovel							1	1
15	Generator							1	1
16	Crawler drill							1	1
17	Air compressor							1	1
18	Asphalt distributor					2			2
19	Asphalt kettle					2			2
20	Asphalt sprayer					4			4
21	Air compressor					2			2
22	Hand guide roller					4			4
23	Concrete cutter					1			1
24	Line maker					1			1
25	Rammer					4			4
26	Chip spreader					2			2
27	Flatbed truck					2			2
Total		14	14	12	12	27	5	7	91

Source: RCC

Table AP6.3.2 Equipment of Prey Veaeng Province

No.	Type	Year	Made	Capacity	Weight/Volume	Quality	Remarks
1	Back Hoe	1987	USSR	180 hp	2.4 - 0.4 m3	60%	Working
2	Crane Kras	1985	USSR	240 hp	12 T	40%	Not working
3	Dump Truck Kamaz	1984	USSR	210 hp	7 m3	40%	Not working
4	Dump Truck Maz	1987	USSR	180 hp	6 m3	70%	Working
5	Dump Truck Maz	1987	USSR	180 hp	6 m3	70%	Working
6	Lorry Truck Kamaz	1987	USSR	210 hp	12 T	70%	Working
7	Lorry Truck Kamaz	1987	USSR	210 hp	12 T	65%	Working
8	Motor Grader	1987	USSR	130 hp	3.2 m	70%	Working
9	Roller	1984	USSR	48 hp	6 T	40%	Not working
10	Roller	1989	USSR	48 hp	6 T	80%	Working
11	Water Tank Maz	1987	USSR	180 hp	8000 L	70%	Working
12	Wheel Loader	1987	USSR	140 hp	2.2 m3	75%	Working

Source: MPWT surveyed in 2003

Table AP6.3.3 Equipment of Svay Rieng Province

No.	Type	Year	Made	Capacity	Weight/Volume	Quality	Remarks
1	Bulldozer	1986	USSR	140 hp	17 T	70%	Working
2	Bulldozer	1987	USSR	140 hp	17 T	70%	Working
3	Crane Kras	1987	USSR	240 hp	12 T	80%	Working
4	Dump Truck Kamaz	1987	USSR	210 hp	7 m3	70%	Working
5	Dump Truck Maz	1986	USSR	180 hp	6 m3	70%	Working
6	Dump Truck Maz	1986	USSR	180 hp	6 m3	70%	Working
7	Dump Truck Maz	1986	USSR	180 hp	6 m3	80%	Working
8	Dump Truck Maz	1986	USSR	180 hp	6 m3	70%	Working
9	Dump Truck Maz	1986	USSR	180 hp	6 m3	70%	Working
10	Excavator	1987	USSR	140 hp	0.7 m3	60%	Working
11	Excavator	1986	USSR	140 hp	0.7 m3	40%	Not Working
12	Fuel Truck	1987	USSR		1000 L	80%	Working
13	Fuel Truck Maz	1986	USSR	180 hp	8000 L	70%	Working
14	Generator	1986	USSR	25 hp		80%	Working
15	Generator	1986	USSR	25 hp		80%	Working
16	Lorry Trucl Kamaz	1988	USSR	210 hp	12 T	70%	Working
17	Motor Grader	1986	USSR	130 hp	3.2 m	70%	Working
18	Roller	1987	USSR	48 hp	6 T	70%	Working
19	Roller	1984	Denmark	44 hp	8 T	70%	Working
20	Truck Trailer Kras	1987	USSR	240 hp	22 T	80%	Working
21	Water Truck Maz	1986	USSR	180 hp	8000 L	80%	Working
22	Welding Engine	1987	USSR	160 hp		80%	Working
23	Wheel Loader	1987	USSR	140 hp	2.2 m3	70%	Working

Source: MPWT surveyed in 2003

Table AP6.3.4 Equipment of Kandal Province

No.	Type	Year	Made	Capacity	Weight/Volume	Quality	Remarks
1	Bulldozer	1998	USSR	140 hp	17 T	70%	Working
2	Concrete Mixer	1989	USSR	25 hp	0.1 T	80%	Working
3	Crane Zil	1987	USSR	160 hp	5 t	70%	Working
4	Crane Zil	1987	USSR	160 hp	5 t	70%	Working
5	Cut Machine	1998	USSR	12 hp	0.2 T	80%	Working
6	Dump Truck	1986	USSR	210 hp	7 m3	70%	Working
7	Dump Truck	1986	USSR	210 hp	7 m3	70%	Working
8	Dump Truck	1986	USSR	210 hp	7 m3	70%	Working
9	Dump Truck	1986	USSR	210 hp	7 m3	70%	Working
10	Dump Truck	1986	USSR	210 hp	7 m3	70%	Working
11	Dump Truck	1987	USSR	180 hp	6 m3	80%	Working
12	Dump Truck	1987	USSR	180 hp	6 m3	60%	Working
13	Dump Truck	1987	USSR	180 hp	6 m3	60%	Working
14	Dump Truck	1987	USSR	180 hp	6 m3	70%	Working
15	Dump Truck	1987	USSR	180 hp	6 m3	60%	Working
16	Dump Truck	1987	USSR	160 hp	5 m3	70%	Working
17	Dump Truck	1987	USSR	160 hp	5 m3	70%	Working
18	Dump Truck	1987	USSR	160 hp	5 m3	70%	Working
19	Excavotor	1987	USSR	140 hp	0.7 m3	70%	Working
20	Excavotor	1987	USSR	140 hp	0.7 m3	70%	Working
21	Lorry Truck	1987	Germany	160 hp	8 T	75%	Working
22	Lorry Truck	1986	USSR	210 hp	12 T	20%	Not Working
23	Lorry Truck	1983	USSR	210 hp	12 T	20%	Not Working
24	Lorry Truck	1986	USSR	210 hp	12 T	70%	Working
25	Lorry Truck	1986	USSR	210 hp	12 T	70%	Working
26	Lorry Truck	1986	USSR	210 hp	12 T	70%	Working
27	Motor Grader	1987	USSR	130 hp	3.2m	70%	Working
28	Pickup Truck	1989	USSR	60 hp	0.4 T	20%	Not Working
29	Roller	1989	USSR	62 hp	9 T	80%	Working
30	Roller	1987	USSR	48 hp	6 T	70%	Working
31	Roller	1989	USSR	62 hp	9 T	80%	Working
32	Roller	1987	USSR	48 hp	6 T	70%	Working
33	Touris Laz	1983	USSR	60 hp	0.4 T	20%	Not Working
34	Water Truck	1986	USSR	180 hp	8000 L	70%	Working
35	Water Truck	1986	USSR	180 hp	8000 L	70%	Working
36	Wheel Loader	1989	USSR	140 hp	2.2 m3	60%	Working

Source: MPWT surveyed in 2003

AP6.4 Application of Toll System for the Project

(1) Traffic Demand by Toll Level

1) Assumptions

a. Annual Traffic Volume

As analyzed in Chapter 3 of the main text, the annual traffic volume is calculated as follows:

Annual traffic volume = average weekday traffic (from traffic survey) x 0.97 x 365

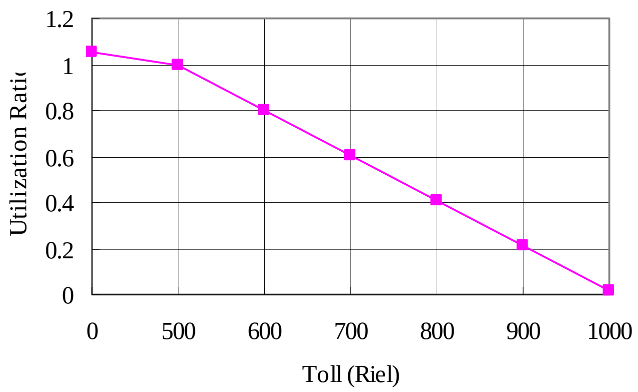
b. Estimation for toll free case

Elasticity between the toll and the traffic volume is analyzed, based on the results of "willingness to pay survey", which was conducted by the Study Team in May 2004. In every case, it is assumed that the traffic demand in "Base Case[1]" could increase as little as by 5%, when the toll is set free. This is because most of the ferry users at Neak Loeung are medium and long distance travelers and the traffic demand at Neak Loeung could be hardly restricted by a change in the current tariff level, accordingly.

2) Elasticity Analysis

a. Motorcycle (MC)

The survey reveals the following relationship between the toll and the motorcycle traffic.



Source: JICA Study Team

Figure AP6.4.1 Demand Elasticity by Toll (MC)

[1] "Base Case" is defined that the existing ferry keeps operating in future

Traffic demand elasticity straightly decreases from 500 Riel to 1000 Riel and the current 500 Riel toll gives the maximum revenue.

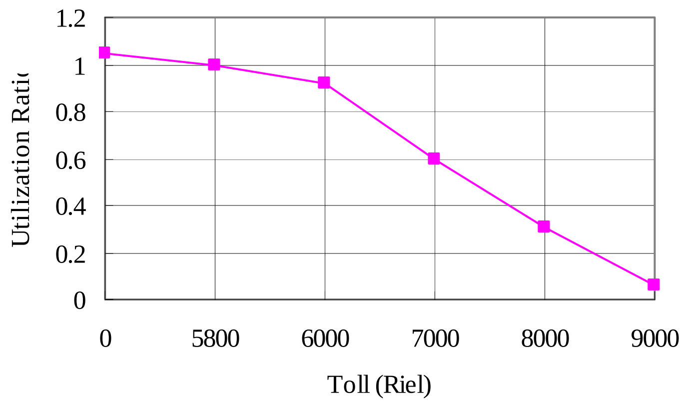
Table AP6.4.1 Change of Revenue (MC)

Toll (Riel)	Expectation	Revenue (Riel)
500	1.00	500
600	0.80	482
700	0.61	426
800	0.41	330
900	0.22	194
1000	0.02	20

Source: JICA Study Team
Note: Revenue=Toll x Expectation ratio

b. Light Vehicle (LV)

The survey reveals the following relationship between the toll and the light vehicle traffic.



Source: JICA Study Team

Figure AP6.4.2 Demand Elasticity by Toll (LV)

Although the elasticity changes at 6000 Riel, 5800 Riel gives the maximum revenue.

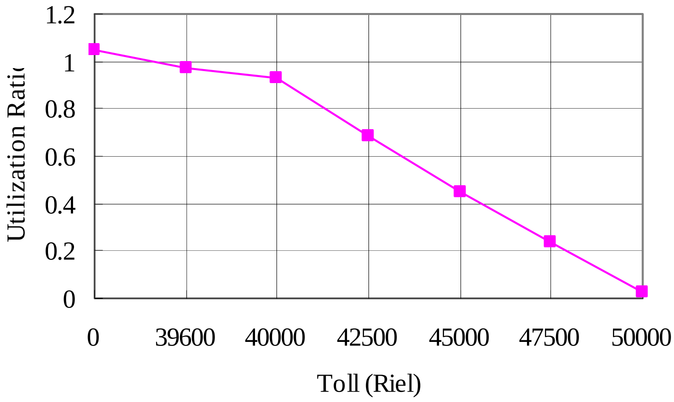
Table AP6.4.2 Change of Revenue (LV)

Toll (Riel)	Expectation	Revenue (Riel)
5,800	0.99	5,756
6,000	0.92	5,523
7,000	0.59	4,154
8,000	0.31	2,481
9,000	0.06	542

Source: JICA Study Team
Note: Revenue=Toll x Expectation ratio, As the utilization is obtained by regression equation, that of toll 5800 Riel is not 1.0.

c. Truck (HV)

The survey reveals the following relationship between the toll and the heavy vehicle traffic.



Source: JICA Study Team

Figure AP6.4.3 Demand Elasticity by Toll (HV)

The elasticity changes at 40,000 Riel. The current toll, 39,600 Riel gives the maximum revenue though the expectation ratio is not 1.0 as the traffic consists of both, short and long trucks, and semi and full trailers.

Table AP6.4.3 Change of Revenue (HV)

Toll (Riel)	Expectation	Revenue (Riel)
39,600	0.97	38,410
40,000	0.93	37,168
42,500	0.68	29,046
45,000	0.45	20,327
47,500	0.23	11,045
50,000	0.025	1,229

Source: JICA Study Team
Note: Revenue=Toll x Expectation ratio

(2) Unified Vehicle Types, Toll Rates and Revenue

1) Current Tariff of Neak Loeung Ferry

a. Tariff by Vehicle Category

Ferry users buy tickets prior to boarding. The current fare is categorized into 11 types based on size and weight of vehicles. There are many pedestrian and pedal-cycle users. The current ferry tariff is tabulated in Table AP6.4.4.

Table AP6.4.4 Current Ferry Tariff in 2004

Category		Riel	US$
1	Passenger only	100	0.02
2	Bicycle and passenger with luggage	200	0.05
3	Motorcycle	500	0.12
4	Ox-cart / trailer	1,000	0.25
5	Sedan 1 (5 and less seats)	5,800	1.43
6	Sedan 2 (6-12 seats)	8,500	2.09
7	Sedan 3 (13-30 seats and less than 5 tons)	12,600	3.10
8	Truck 1 (more than 21 passengers and 6-8 tons)	23,600	5.80
9	Truck 2 (9-15 tones)	39,600	9.74
10	Truck 3 (16-18 tons)	45,500	11.19
11	Truck 4 (more than 18 tones)	52,800	12.98

Source: MPWT

b. Revenue

The past annual revenue by the ferry operation is set forth as follows:

Table AP6.4.5 Past Revenue by Ferry

Year	Income (Million Riel)	Income (1000 US$)
1998	2,851	0.70
1999	3,266	0.80
2000	3,640	0.90
2001	3,665	0.90
2002	3,380	0.83
2003	3,475	0.85

Source: MPWT

c. Estimated Fare Collecting Ratio

As mentioned before, AADT (Annual Average Daily Traffic) is estimated to be almost the same as the result of average weekday traffic volume, obtained by the traffic survey in 2004. According to the analysis by the Study Team, the effective fare collection ratio falls in around 80% of the total traffic volume using the ferry.

2) Unification of Vehicle Categories

The tariff of the current ferry is divided into 11 categories. All ferry users get a ticket in advance when they are on board. This enables the ferry ticket-operators to deal with many ticket-categories. It is necessary to unify toll categories for the toll road with a view to shortening the toll collecting time and easily managing toll collection. Otherwise serious traffic jam may happen. The following toll categories are practically considered:

- Motorcycle (Motorcycle, Motorcycle trailer);
- Light Vehicle (Sedan Jeep, Wagon, Pick up);
- Minibus(6-12 seater);
- Bus and Truck (Large bus, 3 axles and less-truck); and
- Heavy Truck (4 axles and more, semi and full-trailer).

Based on the current ferry tariff, new toll rates corresponding to the unified five (5) vehicle categories are derived as shown in Table AP6.4.6.

Table AP6.4.6 Tariff Equivalent to Current Ferry Service

Type	Riel	US$
Motorcycle	500	0.12
Light Vehicle	5,800	1.43
Minibus	8,500	2.09
Bus and Truck	25,000	6.15
Heavy Truck	49,000	12.05

Source: JICA Study Team

3) Revenue at Equivalent Toll to Ferry

Based on the forecast of future traffic demand (Base Case), the annual revenue from the toll bridge operation is estimated as shown in Table AP6.4.7.

Table AP6.4.7 Estimated Annual Revenue at Toll Equivalent to Ferry Tariff

Year	2012	2013	2014	2015	2016	2017
$ Million	3.03	3.21	3.38	3.55	3.78	4.01

Source: JICA Study Team
Note: Toll collecting ratio is reasonably assumed at 80%, Constant price in 2005

Owing to the above estimate, considerable amount of $3.03 million revenue is expected in 2012, opening year of the bridge under the condition that the same toll as the ferry is applied to the bridge users.