CHAPTER 4

SELECTION OF OPTIMUM CROSSING ROUTE AND METHOD

4. SELECTION OF OPTIMUM CROSSING ROUTE AND METHOD

4.1 Overall Methodology

4.1.1 Overall Procedure

The overall procedure to select the optimum method of the Mekong River Crossing in the study had five main steps as shown in Figure 4.1.1: setup of alternative crossing methods, analysis of critical aspects, setup of alternatives for comparative evaluation, comparative evaluation of alternatives, and selection of the optimum alternative. Each step is described below.

(1) Setup of Alternative Crossing Methods

Alternative facilities or methods capable of providing crossing services over the Mekong River at Neak Loeung are enumerated, and they will generally include such options as a ferry, bridge and tunnel.

(2) Analysis of Critical Aspects

Before engaging in comparative study in more detail, critical aspects of the alternatives, which would be fatal to selecting the optimum solution, are analyzed for the initial screening out of poor alternatives.

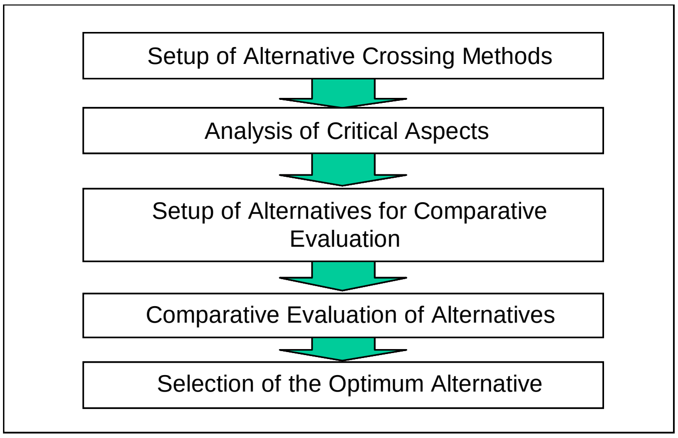


Figure 4.1.1 Overall Study Steps for Selecting the Optimum Alternative

(3) Setup of Alternatives for Comparative Evaluation

After eliminating an alternative that is apparently unrealistic or impractical, remaining alternatives are adopted for further comparative analysis.

(4) Comparative Evaluation of Alternatives

Analytic Hierarchy Process (AHP) is a comparative evaluation method characterized by the application of multiple criteria of either qualitative or quantitative factors. Therefore, this method is employed for a project structured with different levels and having various attributes of criteria.

(5) Selection of the Optimum Alternative

Among the candidate alternatives, an optimum alternative is selected as the result of AHP.

A major workflow for selecting the optimum alternative is presented in Figure 4.1.2.

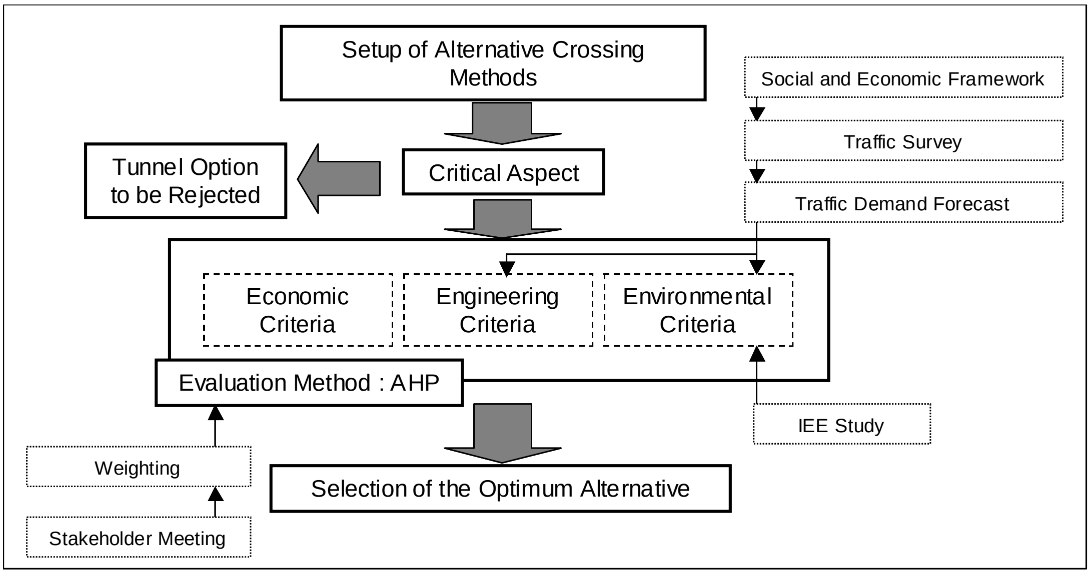


Figure 4.1.2 Major Work Flow for Selecting the Optimum Alternative

4.1.2 Setup of Alternative Crossing Methods

Alternative facilities or methods to be considered to cross the river will be confined to boat (ferry), bridge and tunnel. The construction costs of these alternatives are higher in this order in general, but the investment efficiency depends on traffic demand, required height of navigation clearance, depth of water and other natural conditions in particular.

Crossing alternatives conceivable for the comparative analysis should include “zero option”, i.e. “do nothing” or “without project” case and a combination of the alternatives in time horizon, such as “bridge” construction after “ferry improvement” [1]. As the consequence, four possible alternatives to cross the river are envisaged as shown in Table 4.1.1.

Table 4.1.1 Possible Alternatives of the River Crossing Method

1. Ferry	Zero Option (No improvement but appropriate maintenance)
	Ferry Improvement by increasing the ferry capacity and/or number of ferries
2. Bridge	
3. Combined Option of Ferry Improvement and then Bridge	
4. Tunnel	

4.1.3 Analysis of Critical Aspect

A tunnel is a candidate alternative, only if it is worth comparing, in terms of costs, with a bridge that requires a high vertical clearance for the navigation of high mast vessels. However, it is not a general practice in the world to construct a tunnel in an area always threatened with flooding.

Planning of a tunnel in the Neak Loeung area would incur the following problems and issues:

[1] One ferry boat with its capacity of 24 PCU was replaced to Neak Loeung in 2005 and totally three ferry boats are in service. Accordingly, the total capacity of three ferries reaches 4,548 PCU with 36 minutes waiting time, and that can bear the future traffic demand by 2012, as studied in Chapter 3.

1) Designing the tunnel openings at a safe height should securely prevent influx water by the flooding, and which eventually requires a tall and continuous embankment. Although an automatic gate is often installed to protect a subway entrance, good maintenance and management would be required for the automatic gate operation.

2) Maintenance and management is crucial to keep the tunnel operational and safe, and such costs are considerably high and include ventilation, lighting and drainage of rainwater brought in by vehicles and river water spilled from the tunnel joints.

3) Once flooding submerges the tunnel, it needs significant costs not only to recover, but also to provide a substitute means to cross the river.

As the consequence of the critical aspect analysis, the tunnel alternative should be eliminated, in this initial step, from candidate alternatives of the crossing method.

4.1.4 Application of Analytic Hierarchy Process (AHP)

(1) What is AHP

AHP, as conceptually outlined in Figure 4.1.3, has been applied in a wide variety of applications, multi-criteria decision-making being just one. There are three primary functions of the AHP: namely, structuring complexity, measurement, and synthesis.

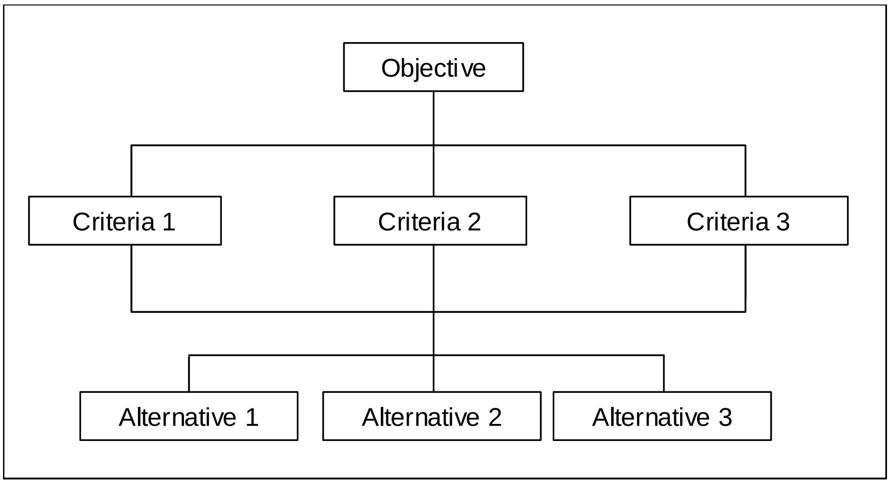


Figure 4.1.3 Conceptual Structure of Multi-Criteria Decision Making Process (AHP)

The foundation of AHP is a set of axioms that carefully delimit the scope of the problem environment. It is based on the well-defined mathematical structure of consistent matrices and their associated right-eigenvector's ability to generate true or approximate weights. The AHP methodology compares criteria or alternatives with respect to each criterion, in a natural, pair-wise mode. To do so, AHP uses a fundamental scale of absolute numbers that has been proven in practice and validated by physical and decision problem experiments. The fundamental scale has been shown to be a scale that captures individual preferences with respect to quantitative and qualitative attributes just as well or better than other scales. It converts individual preferences into ratio scale weights that can be combined into a linear additive weight w(a) for each alternative a. The resultant w(a) can be used to compare and rank the alternatives and, hence assist the decision maker in making a choice.

(2) AHP (1) and AHP (2)

The bridge alternative in particular involves a critical factor such as a route option that affects significantly the viability of the project and as a determinant of the alternative evaluation. Accordingly, the comparative evaluation of the alternatives is made in two steps as shown in Figure 4.1.4. That is, the first step determines the optimum route of the bridge option and the second step compares among the bridge, ferry and the combination of the two.

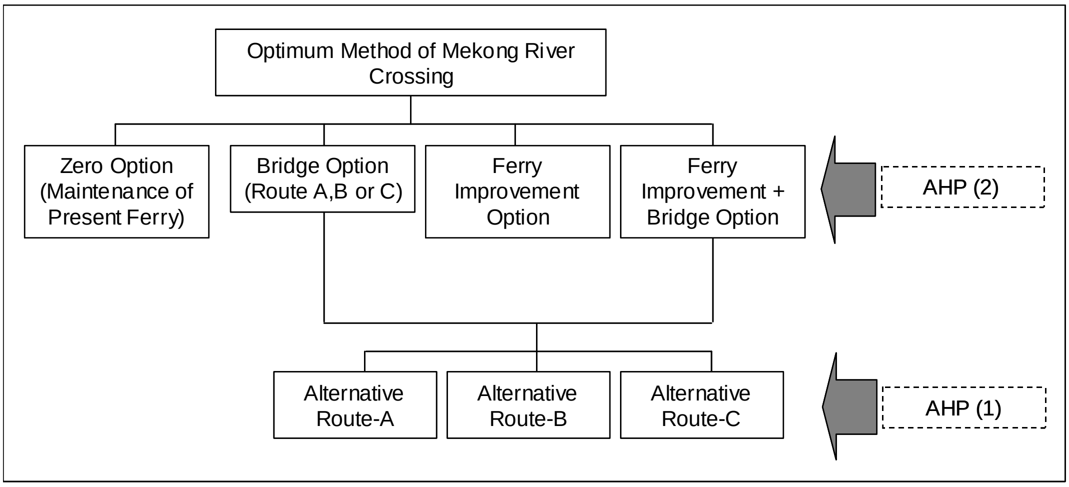


Figure 4.1.4 Phased Application of AHP to Multi Layered Alternatives

(3) Selected Evaluation Criteria

Alternatives of the bridge route as well as those of the crossing methods are evaluated by criteria, which are common in the respective steps of AHP (1) and AHP (2).

The criteria are structured at primary, secondary and tertiary levels. The primary level is comprised of such criteria as “Engineering”, “Economy” and “Environment”, and which are commonly applied to both AHP (1) and AHP (2). The secondary level of the “Environmental” criteria consists of “Natural” and “Social” criteria, and the tertiary level includes more detailed sub-criteria as summarized in Table 4.1.2.

Sub-criteria used for the comparative evaluation are derived from the workshops held at the stakeholder meetings where the problem identifications and the scope of Initial Environmental Examination (IEE) are discussed. Detail attributes of the tertiary level criteria are described in Table 4.1.3.

Table 4.1.2 Structured Evaluation Criteria Common in AHP (1) and AHP (2)

Primary Level Criteria	Secondary Level Criteria	Tertiary Level Criteria
Engineering Criteria	n.a.	Stability of Crossing Service
		Safety of Crossing Service
		Sustainability of Crossing Service
Economic Criteria	n.a.	Appropriateness to Traffic Demand
		Investment Efficiency
		Impacts on Regional Economy
Environmental Criteria	Natural Environment	Noise and Vibration
		Traffic Accidents
		Other Impacts on Natural Environment

Primary Level Criteria	Secondary Level Criteria	Tertiary Level Criteria
	Social Environment	Involuntary Resettlement
		Impacts on Land Use
		Impacts on Local Livelihood
		Other Impacts on Social Environment

Table 4.1.3 Description of the Evaluation Criteria for AHP (1)

1. Engineering Criteria

No.	**Description of Engineering Criteria**
1	Stability of Crossing Service
	• Whether or not the alternative will be able to provide users with stable crossing service. • Whether or not the alternative will be able to regularly provide users with on-time crossing service.
2	Safety of Crossing Service
	• Whether or not the alternative will be able to provide users with safe crossing service.
3	Sustainability of Crossing Service
	• Whether or not the alternative will be able to provide users with crossing service in longer term. • Whether or not facilities of the alternative will be durable in longer term.

2. Economic Criteria

No.	**Description of Economic Criteria**
1	Appropriateness to Traffic Demand
	• Whether or not the alternative will be able to meet the international transportation demand. • Whether or not the alternative will be able to meet the domestic transportation demand. • Whether or not the alternative will be able to significantly save the waiting time of users.
2	Investment Efficiency
	• Whether or not the alternative will be able to generate sufficient benefits or returns against the huge investment cost. • Whether or not the operation and maintenance cost will be affordable.
3	Impacts on Regional Economy
	• Whether or not the alternative will be able to contribute to the development of the national and regional economy.

3. Natural Environmental Criteria

No.	**Description of Natural Environmental Criteria**
1	Noise and Vibration
	• Whether or not the increased traffic caused by the alternative will bring about serious negative impacts on noise and vibration around the project area.
2	Traffic Accidents
	• Whether or not the increased traffic caused by the alternative will bring about possibility of increasing the risk of various traffic accidents.
3	Other Natural Environmental Impacts

	• Whether or not the alternative will worsen air quality around the project area. **(Air Quality)** • Whether or not the alternative will worsen the water quality around the project area. **(Water Quality)** • Whether or not the alternative will badly affect the soil and sedimentation around the project area. **(Soil and Sedimentation)** • Whether or not the alternative will generate considerable amount of waste disposal. **(Waste Disposal)** • Whether or not the alternative will cause the subsidence around the project area. **(Subsidence)** • Whether or not the alternative will cause bad smells around the project area. **(Bad Smells)** • Whether or not the alternative will badly affect topographical and geological situations around the project area. (Topography and Geology) • Whether or not the alternative will badly affect riverbed materials of the river. **(River Bed Materials)** • Whether or not the alternative will badly affect fauna and flora around the project area. **(Fauna and Flora)** • Whether or not the alternative will badly affect quality and quantity of water recourses around the project area. **(Use of Water Resources)** • Whether or not the alternative will increase the risk of the greenhouse effect gas (CO_2), which might cause the global warming. **(Greenhouse Effect Gas)**

4. Social Environmental Criteria

No.	Description of Social Environmental Criteria
1	Involuntary Resettlement
	• Whether or not the scale of the involuntary resettlement caused by the alternative will be considerably large. • Whether or not the involuntary resettlement caused by the alternative will be considerably serious.
2	Impacts on Land Use
	• Whether or not the alternative will generate positive impacts on the land use around the project area. (For example, the bridge alternative will generate flood-free land through the construction of the approach road.) • Whether or not the alternative will have negative impacts on the land use around the project area. (For example, negative impacts on fishing or farming production in the flood-free land will be generated by the construction of the approach road.)
3	Impacts on Local Livelihood
	• Whether or not the alternative will affect women's and children's income and jobs around the ferry crossing area. • Whether or not the alternative will affect other socially vulnerable people.
4	Other Impacts on Social Environment
	• Whether or not the alternative will favorably or badly affect accessibility to various social facilities such as schools, medical services, market, and etc. **(Social Infrastructure)** • Whether or not the alternative will equally provide people with benefits and losses accruing from the project. **(Equality of Losses and Benefits)** • Whether or not the alternative will bring about local conflicts of interests. **(Local Conflicts of Interests)** • Whether or not the alternative will badly affect local cultural heritage. **(Cultural Heritage)** • Whether or not the alternative will have the possibility of increasing the risk of HIV/AIDS. **(Infectious Diseases)**

5. Overall Priority on 3 Categories of Criteria

Engineering Category of Criteria	
1	Stability of Crossing Service
2	Safety of Crossing Service
3	Sustainability of Crossing Service
Economic Category of Criteria	
1	Appropriateness to Traffic Demand
2	Investment Efficiency
3	Impacts on Regional Economy
Environmental Category of Criteria	
a. Natural Environment	
1	Noise and Vibration
2	Traffic Accidents
3	Other Impacts on Natural Environment
b. Social Environment	
1	Involuntary Resettlement
2	Impacts on Land Use
3	Impacts on Local Livelihood
4	Other Impacts on Social Environment

(4) Preference of Stakeholders to Evaluation Criteria

1) Interview Survey to Stakeholders

In order to survey the preference of stakeholders of the evaluation criteria, a questionnaire interview survey was undertaken. The total number of sampled interviewees (excluding MPWT and the Study Team) was 135 persons and the actual acceptance of the interview survey was 104 persons, of which the effective sample amount was eventually 91 persons.

2) Method of Comparison

A pair-wise comparison of criteria on the same level is valued following the scale of relative importance defined in Table 4.1.4.

Table 4.1.4 Scale of Relative Importance

Intensity of Relative Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Slight importance of one over the other	Experience and judgment slightly favor one activity over the other
5	Moderate importance of one over the other	Experience and judgment moderately favor one activity over the other
7	Strong importance of one over the other	Experience and judgment strongly favor one activity over the other
9	Extreme importance of one over the other	Experience and judgment extremely favor one activity over the other
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
A fraction of the above numbers	Reversed judgment against the above case is expressed in the fraction	

Likewise, a pair-wise comparison of alternatives is valued with regard to the respective criteria by the same scale of relative importance. The questionnaire used for the survey is presented in Appendix 2.1 of Interim Report (March 2005).

4.2 Selection of Optimum Crossing Route

4.2.1 Applied Structure of AHP (1)

AHP (1) is initially applied to decide an optimum route of the bridge option, and on this basis an optimum method or facility to cross the River is selected from such alternatives as the bridge with its optimum route, improvement of the existing ferry and the combination of the first two alternative options.

Alternative routes of the bridge option are compared by the evaluation criteria set forth previously in Table 4.1.3 and the scale of relative importance in Table 4.1.4. The entire hierarchy of AHP (1) is structured as shown in Figure 4.2.1.

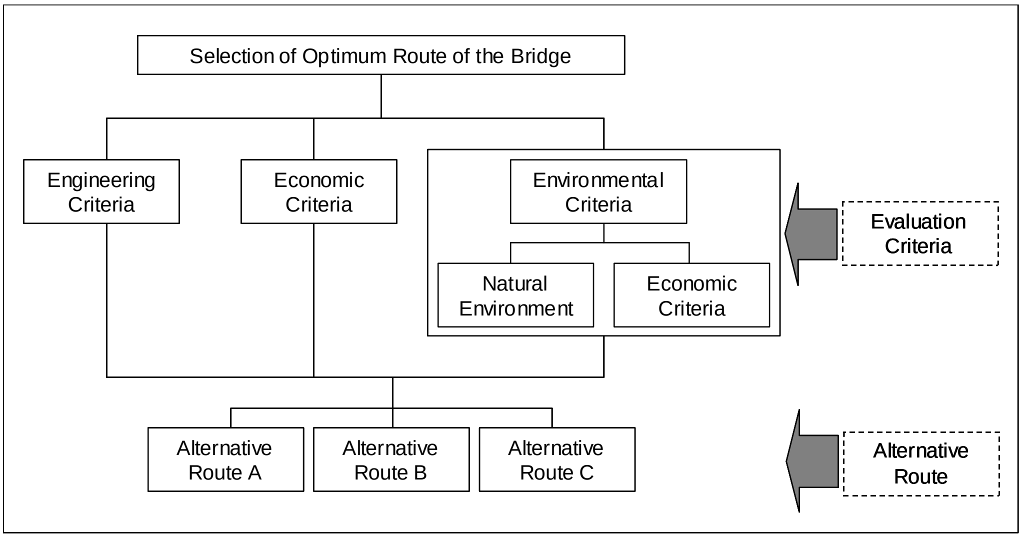


Figure 4.2.1 Entire Hierarchy of AHP (1)

4.2.2 Establishment of Alternative Routes

Considering elements that will significantly affect the evaluation of the bridge location, the following three alternative routes (refer to Figure 4.2.2) are adopted. Their characteristics are summarized in Table 4.2.1 and described below in detail.

Table 4.2.1 Alternative Routes of the Bridge

Major Characteristics	Route A	Route B	Route C
(a) Crossing Distance between the east and west bank of the Mekong River (meter)	1,650	1,250	900
(b) Crossing Distance of the Main Stream (meter) of the Mekong River	600	725	900
(c) Crossing Distance of the Tributary Stream (meter) of the Mekong River	250	200	n.a.

Source: JICA Study Team

Route A:

This is located to the north of Neak Loeung ferry route, and where the Mekong River is split by Phnon Knong Island to main and tributary streams. This route is drawn where the river width of the main stream is the shortest in the Neak Loeung area (about 600 m), and the total of the two river crossings becomes 850 m, which is the shortest among the three alternatives. However, the total distance between the east and west bank of the Mekong River is about 1650 m, which is the longest among the alternatives.

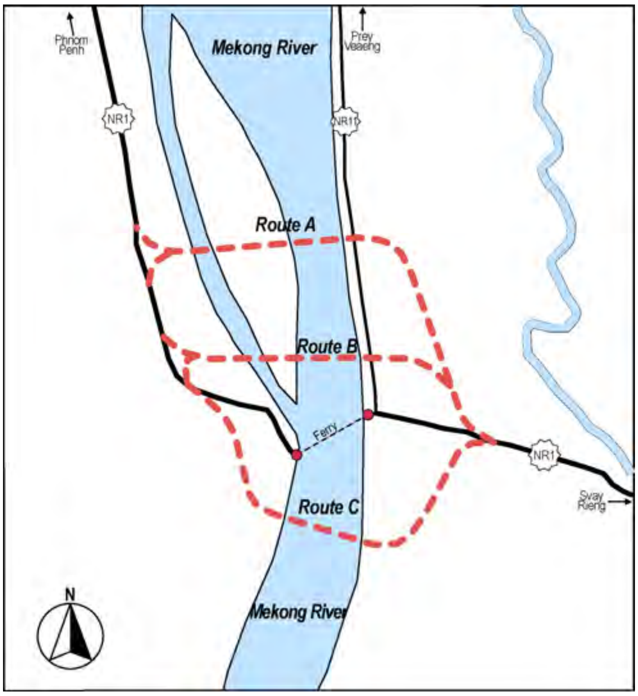


Figure 4.2.2 Alternative Routes of the Bridge in Neak Loeung

Route B:

This is also located to the north of the Neak Loeung ferry route and drawn as close as possible to the existing ferry pier to assure the shortest access to NR-1. Considerations are also given to minimize possible involuntary resettlement. The total resulting distance between the east and west bank of the Mekong River is about 1250 m.

Route C:

This route is located to the south of Neak Loeung ferry route and drawn at the point to minimize the crossing distance over the river, which results in about 900 m.

4.2.3 Evaluation of Weights on Criteria for AHP (1)

Among the primary level criteria, "Engineering Criteria" is considered not relevant to the bridge route selection. Because the bridge should be planned and designed, wherever it is located in the Neak Loeung area, to assure the necessary standard of services such as stability, safety and sustainability. Therefore, results of the questionnaire interview survey to the stakeholders are compiled only with regard to "Economic" and "Environmental" Criteria, and are presented in detail in Appendix 4.2 and summarized in Table 4.2.5.

According to the survey, it was found that:

- The stakeholders, except for Donors, place dominant importance (more or less 80%) on the "Economic Criteria" than "Environmental Criteria". The Donor group allocates relatively higher importance to "Environmental Criteria"(about 60%) than "Economic Criteria"(about 40%).
- If compared between "Natural" and "Social" environment, NGO and Research Institute put more importance on "Social", whereas Neak Loeung Ferry and Villagers put more importance on "Natural" Environment.
- Among the sub-criteria of "Economic", all the stakeholder groups show more important concern with "Appropriateness to Traffic Demand" rather than "Investment Efficiency" or "Impacts on Regional Economy".
- Among the sub-criteria of "Social Environment", "Involuntary Resettlement" indicates relatively higher rating than others, but the difference is not significant from "Impacts on Land Use" and "Impacts on Local Livelihood".

4.2.4 Evaluation of Alternative Routes by Criteria

The Alternative Route A, B and C are technically compared with respect to the "Economic" and "Environmental" evaluation criteria. In order to undertake a down-to-earth comparison of the alternatives, more detailed attributes to the sub-criteria are analyzed with technical aspects such as length of bridge structure, length of approach road, traffic flow changes, project costs, geotechnical conditions, and so forth as introduced in Table 4.2.2.

Based on the analytical result of these attributes, comparative evaluation of the alternative routes was made by the Study Team and results are shown in Table 4.2.3.

Table 4.2.2 Descriptive Evaluation of Alternative Routes from Technical Aspect

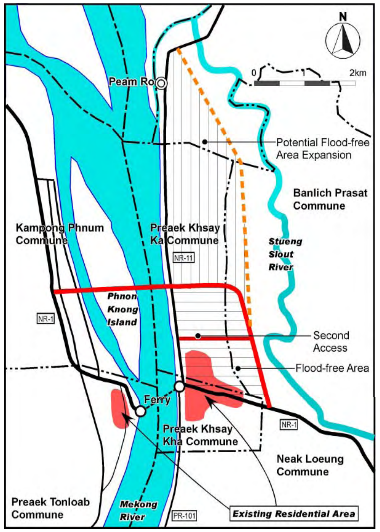
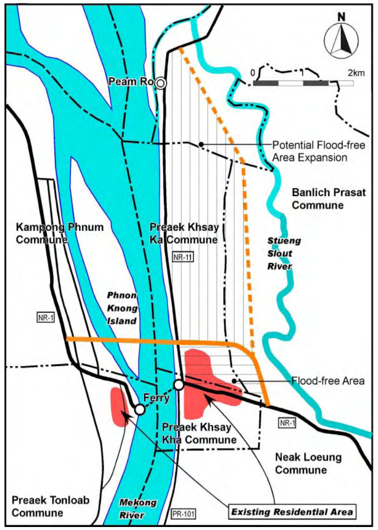
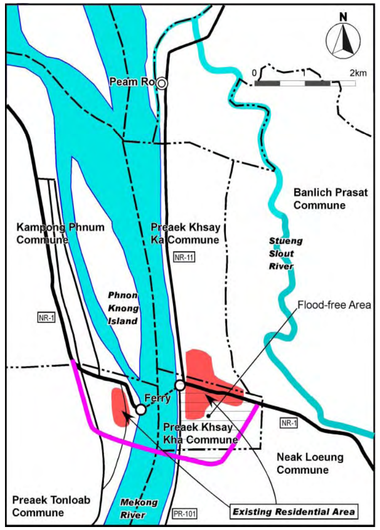
Route	Alternative Route-A (Northern Route)	Alternative Route-B (Central Route)	Alternative Route-C (Southern Route)
(1) Location			
(2) Characteristics of Alternative Route	• Total Bridge Length : 2.230m • Approach Road Length : 2,565 m	• Bridge Length : 2,030m • Approach Road Length : 2,065 m	• Bridge Length : 2,030 m • Approach Road Length : 2,480 m
(3) Condition of Main River	• Width of main flow is 600m in the rainy season. • Maximum depth of the Main flow is -22 MSL.	• Width of main flow is 670m in the rainy season • Maximum depth of the Main flow is -22 MSL.	• Width of main flow is 870m in the rainy season. • Maximum depth of the Main flow is -22 MSL.
(4) Condition of Channel between Kompon Phnum and Phnom Knong Island	• The channel run dry during the dry season	• Water in channel remain through the year. Width of Channel : 350m	• No channel
(5) Consistency with Local traffic	• Approach road will have a function of bypass road connecting NR-1 and NR-11	• Approach road will have function of bypass road connecting NR-1 and NR-11	• Vehicles on NR-1 to and from NR-11 have to pass through down town of Neak Loeung
(6) Accessibility to the resident area on both side of the River Bank	• Road length between Neak Loeung and Kampong Chamlan is 6.6	• Road length between Neak Loeung and Kampong Chamlan is 5.9 km	• Road length between Neak Loeung and Kampong Chamlan is 5.6 km
(7) Access to the Phnom Knong Island	• Access to the island could be provided utilizing a temporally bridge for the construction of Main Bridge	• Access to the island could be provided utilizing a temporally bridge for the construction of Main Bridge	• Access to the Phnom Knong Island could not be provided
(8) Possibility of erosion of the Bank	• There are some possibilities of erosion of the eastern bank of Phnom Knong Island side	• There are some possibilities of erosion of the eastern bank of Phnon Knong Island	• Both side of the river banks are stable
(9) Involuntary resettlement and type of resident	• Number of houses to be resettled will amount to 51. • Majority of resident is farmer and the wooden house with thatched roof	• Number of houses to be resettled will amount to 69. • Majority of resident are citizens of Neak Loeung. Many wooden or concrete houses including Government offices.	• Number of houses to be resettled will amount to 65. • Majority of resident is Vietnamese along the Mekong River living in the raised house. Many of houses are wooden house with thatched
(10) Impact to the approach road by the flood flow from the Stueng Slout River	• Slight impact by the flood flow will be expected to the embankment of approach road. Velocity of the flood flow along the north-south section of the embankment is estimated at 1.0m/sec and erosion of embankment shall be minded. East-west section of the embankment connect with NR-11 create a dead water zone.	• Situation is similar to the Alternative Route-A	• The embankment of the approach road is not affected by the flood flow, since the flood flow from Stueng Slout River is dammed up by NR-1. Base of embankment is immersed by the back water from the flood plain.
(11) Depth to the basement rock	• Depth to the hard stratum at left bank is -40m and right bank is 38m	• Depth to the hard stratum at left bank is -49m and right bank is -50m	• Depth to the hard stratum at left bank is -40m and right bank is -21m
Flood-Free Land			
(12) Condition of Embankment	• Surrounded by the embankment of NR-11, NR-1 and the approach road of bridge • A slope inside the embankment have to be protected by sodding. Outside of embankment needs a suitable protection.	• Almost the same as Alternative Route-A	• Surrounded by the embankment of PR-101, NR-1 and the approach road of bridge. • Need to raise a ground level of PR-101 against the flood flow from Mekong River
(13) Suitability for Land Diversion	• Recommendable to slot this area into urban area.		• This area is suitable for agriculture compared to Alternatives A & B
(14) Drainage system	• Duration of inundation in this area continue about 3-4 months, and the altitude of inside of the embankment is relatively low compared to the high water level. Drainage of water inside the embankment shall be done by pumping or by the manmade pond.		• Since the altitude in this area is relatively higher than the areas surrounded by other alternative routes. Natural drainage could be
(15) Possibility of Expansion of Flood-free Land	• Possible to expand the flood-free area far up to Peam Ro • Possible to relocate the provincial government from Prey Veaeng		• It is not recommendable to expand the flood free land in this area , since the height of the river bank is lower than high water level.
(16) Flood-Free Area	• 102 ha	• 56 ha	• 50 ha

Table 4.2.3 Descriptive Comparison of Alternative Routes by Selected Attributes and Criteria

Evaluation Criteria				Attributes	Comparative Evaluation of Alternative Routes
1	**Economic Criteria**				
	1		Appropriateness to Traffic Demand	Traffic Capacity	Since the traffic capacity of the bridge does not vary depending on its location relative importance among the three alternatives is considered the same.
	2		Investment Efficiency	Project Cost* and Benefit	Based on the robust cost estimate, it is found there is no significant difference in costs among the alternative locations, but the benefit derived from the saving in vehicle operating costs of Route-C is reduced by additional approach distance to/from the existing NR-1.
	3		Impact on Regional Economy	Influence on Hinterland Economy	Northern route location of Alternative A is advantageous for easier connectivity to such regional centers as Prey Veaeng, Kampong Cham, Kracheh and those in the northeast and northwest regions.
2	**Environmental Criteria**				
	1	**Natural Environment**			
		1	Noise and Vibration	Distance between the Approach and Urban Area	Route B is nearest among the alternatives to the urban area followed by Route C and Route A.
		2	Traffic Accidents	Separation of Through and Local Traffic	Route A and B have a bypass function for such through traffic as Svay Rieng-Phnom Penh and Svay Rieng-Kampong Cham, while Route C can not provide the bypass function for Svay Rieng-Kampong Cham traffic. Route B, if compared to A, is closer to the residential area.
		3	Other Impacts	Since there are no significant differences in natural conditions along the alternative routes, other natural impacts by the alternative routes are considered equal.	
	2	**Social Environment**			
		1	Involuntary Resettlement	Number and Structure of Affected Houses	The number of affected houses is smallest for Route A (51), and larger for Route B (69) and Route C (65). The affected houses on Route B are mostly wooden or concrete structures, while those on Route A and C are mostly thatched roof houses.
		2	Impacts on Land Use	Development of Flood-free	As the consequence of the bridge approach road flood-free land is potentially developed, and Route A has the most extensive area followed by Route B. For such a development enclosed by Route C, PR-101 has to be improved additionally.
				Land and Access to Phnon Knong Island	Route A and B will enable the people in Phnon Knong Island to access all the year to the Kandal area.
		3	Impacts on Local Livelihood	Affected people around the Ferry Terminal	Wherever the bridge is constructed, the people living on small business such as vendors, restaurant, and shops around the ferry terminal will loose business opportunities therein. Countermeasures, however, can be potentially taken along with the bridge construction.
		4	Other Impacts	Accessibility to Urban Centers across the river	Many of public facilities are located in and around the center areas facing across the river. Route B and C are shorter in distance, if compared to Route A, between the urban centers at Neak Loeung and Kampong Chamlang.

Source: JICA Study Team
Note *: Please see Table 4.2.4 for details

Table 4.2.4 Preliminary Project Cost Estimates for Alternative Routes

Unit: $Million

Item	A	B	C	Remarks
(1) Construction Cost	54.69	55.50	55.33	
(2) Engineering	5.47	5.55	5.53	(1) x 10%
(3) Contingency	9.02	9.16	9.13	(1+2) x 15%
(4) Land/Compensation	0.24	0.37	0.29	
Project Cost	69.43	70.58	70.28	

Source: JICA Study Team

Based on the comparative analysis of technical attributes, the importance of pair-wise alternative routes is judged and measured by the scale of relative importance. Weights of the alternatives with respect to the sub-criteria are shown in Appendix 4.2 and summarized in Table 4.2.5.

4.2.5 Overall Evaluation of Alternative Routes

Based on the analyses in previous sections 4.2.3 and 4.2.4, the scale ratios (weights) derived from the comparison of each pair of criteria or alternative is summarized by groups of stakeholders, MPWT and the Study Team in Table 4.2.5, and are synthesized to resolve a multi-criteria decision and to best select the highest priority among Alternatives A, B and C.

Priority scale ratios of the alternative routes are derived consequently as shown in Table 4.2.6 and Figure 4.2.3. They reveal, in all groups of stakeholders, MPWT and the Study Team, that Alternative A is given the highest priority (ranging 40.9%~46.1%) followed by Alternative B (32.7%~35.4%) and C (21.3%~24.8%).

Consequently, it is confirmed that all the stakeholder groups as well as MPWT and the Study Team are in agreement on Alternative Route A as the optimum route of the bridge to cross the Mekong River at Neak Loeung.

Table 4.2.5 Summary of Weights on Criteria by Group and on Alternative Routes

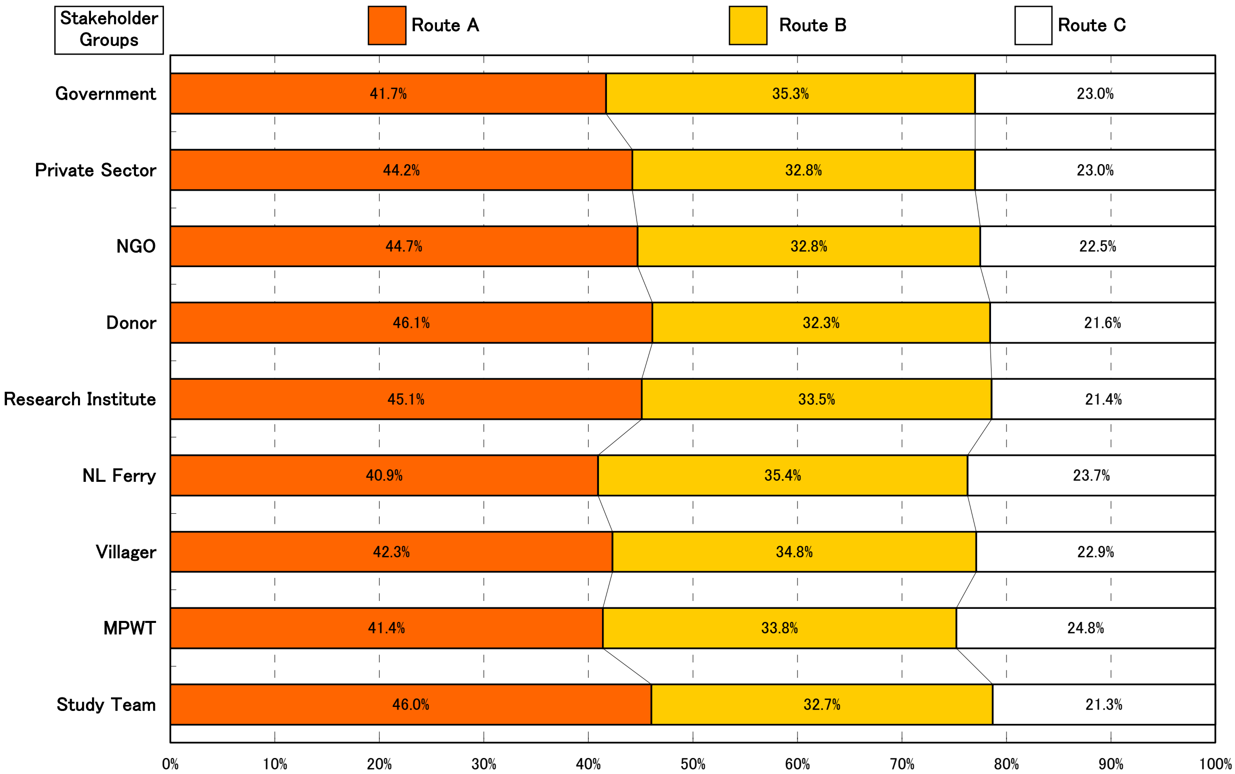
Criteria	1 Government	2 Private Sector	3 NGO	4 Donor	5 Research Institute	6 NL Ferry	7 Villager	8 MPWT	9 Study Team	Route A	Route B	Route C
Economic Criteria	(0.877)	(0.752)	(0.836)	(0.380)	(0.861)	(0.864)	(0.836)	(0.828)	(0.715)			
Appropriateness to Traffic Demand	**0.430**	**0.368**	**0.381**	**0.174**	**0.351**	**0.459**	**0.404**	**0.493**	**0.276**	**0.333**	**0.333**	**0.333**
Investment Efficiency	**0.335**	**0.181**	**0.189**	**0.068**	**0.261**	**0.324**	**0.322**	**0.204**	**0.220**	**0.429**	**0.429**	**0.143**
Impacts on Regional Economy	**0.112**	**0.203**	**0.266**	**0.139**	**0.249**	**0.082**	**0.111**	**0.132**	**0.219**	**0.637**	**0.258**	**0.105**
Environmental Criteria	(0.123)	(0.248)	(0.164)	(0.620)	(0.139)	(0.136)	(0.164)	(0.172)	(0.285)			
Natural Environmental Criteria	(0.065)	(0.147)	(0.055)	(0.310)	(0.039)	(0.107)	(0.110)	(0.054)	(0.086)			
Noise and Vibration	**0.020**	**0.045**	**0.011**	**0.041**	**0.006**	**0.042**	**0.044**	**0.006**	**0.012**	**0.540**	**0.163**	**0.297**
Traffic Accidents	**0.031**	**0.067**	**0.025**	**0.207**	**0.023**	**0.056**	**0.049**	**0.035**	**0.054**	**0.429**	**0.429**	**0.143**
Other Impacts on Natural Environment	**0.014**	**0.035**	**0.019**	**0.062**	**0.010**	**0.009**	**0.016**	**0.013**	**0.019**	**0.333**	**0.333**	**0.333**
Social Environmental Criteria	(0.058)	(0.101)	(0.109)	(0.310)	(0.100)	(0.028)	(0.054)	(0.117)	(0.200)			
Involuntary Resettlement	**0.017**	**0.038**	**0.026**	**0.041**	**0.041**	**0.007**	**0.019**	**0.038**	**0.093**	**0.600**	**0.200**	**0.200**
Impacts on Land Use	**0.018**	**0.021**	**0.021**	**0.126**	**0.019**	**0.011**	**0.020**	**0.023**	**0.032**	**0.731**	**0.188**	**0.081**
Impacts on Local Livelihood	**0.014**	**0.020**	**0.036**	**0.093**	**0.017**	**0.008**	**0.011**	**0.043**	**0.048**	**0.333**	**0.333**	**0.333**
Other Impacts on Social Environment	**0.009**	**0.022**	**0.025**	**0.051**	**0.022**	**0.002**	**0.005**	**0.014**	**0.027**	**0.143**	**0.429**	**0.429**
Total	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**			

Source: JICA Study Team

Table 4.2.6 Overall Evaluation of Alternative Routes for Bridge Option

Stakeholder Groups	Route A	Route B	Route C
Government	0.417	0.353	0.230
Private Sector	0.442	0.328	0.230
NGO	0.447	0.328	0.225
Donor	0.461	0.323	0.216
Research Institute	0.451	0.335	0.214
NL Ferry	0.409	0.354	0.237
Villager	0.423	0.348	0.229
Average of S.H	0.430	0.343	0.227
MPWT	0.414	0.338	0.248
Study Team	0.460	0.327	0.213

Source: JICA Study Team



Source: JICA Study Team

Figure 4.2.3 Overall Evaluation of Alternative Routs for Bridge Option

4.3 Selection of Optimum Crossing Method

4.3.1 Applied Structure of AHP (2)

The objective of AHP (2) is to decide what is the optimum method to cross the Mekong River at Neak Loeung after AHP (1).

AHP (2) is designed as shown in Figure 4.3.1 and it employs the same categories of evaluation criteria used in AHP (1), and the optimum solution to cross the river is eventually selected from the alternative methods.

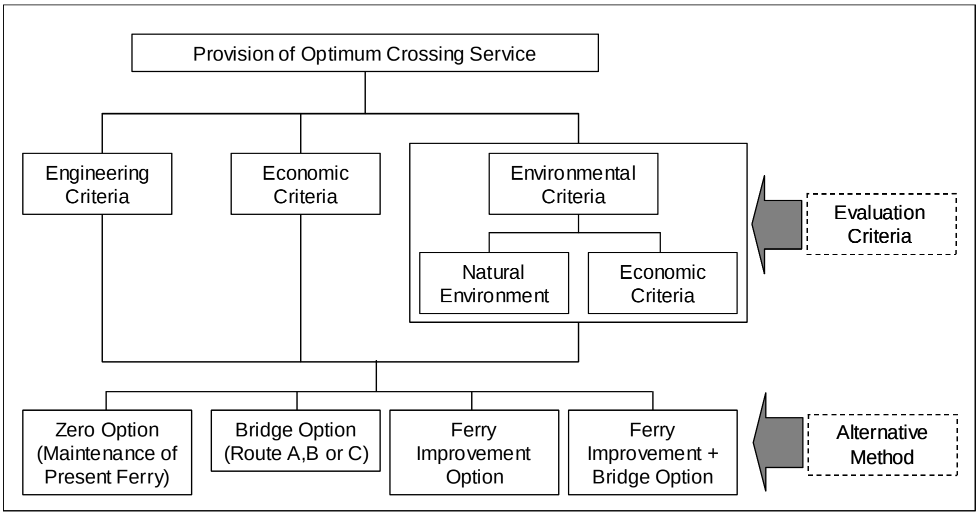


Figure 4.3.1 Entire Hierarchy of AHP (2)

4.3.2 Establishment of Alternative Crossing Methods

(1) Setup of Alternative Crossing Methods

Down-to-earth alternative methods were selected previously in section 4.1.3, where the tunnel option is eliminated from the possible alternative methods and consequently, the bridge and ferry options remain as candidates for the subsequent elaboration of the comparative analysis.

According to the New JICA Guidelines for Environmental and Social Considerations, “Zero Option” or “Without Project Option” has to be incorporated into the alternative options. Furthermore, the combination of the “Ferry Improvement plus Bridge” option is considered as another possible alternative option, since the implementation of the bridge, if selected, takes several years till completion.

Consequently, four alternative methods are selected for the elaboration by AHP (2) and they are summarized as shown in Table 4.3.1.

Table 4.3.1 Selected Alternative Crossing Methods for AHP (2)

No.		Option		Remarks
1. Ferry Option				
	1-1	Ferry	Existing Ferry with Proper Maintenance	Zero Option
	1-2	Ferry Improvement	Upsizing of Ferry Capacity or Additional Ferryboats with Additional Pier	
2. Bridge Option				Route A is selected by AHP (1) as the optimum route
3. Ferry Improvement + Bridge Option (Route A)				

(2) Definition and Description of Alternatives

1) Ferry Option (Zero Option)

This alternative option assumes that the present ferry system is properly maintained and operated as it is. The ferry system at present is generally serviced by two ferries, though they are reduced to one in off peak or increased to three in a special high season. It is assumed that the ferry capacity remains unchanged and the maintenance is undertaken properly.

2) Ferry Improvement Option

This option assumes that the present ferry capacity is improved as the traffic demand increases. The improvement may cover plans such as up-sizing the existing ferry or additional ferry with additional pier.

Since the present ferry operation occasionally adds one ferry, i.e. three ferries in total, when required at special season, it is considered possible to add one more boat in the same route without jeopardizing the present ferry navigation. Therefore, the present ferry capacity can be increased by the same or slightly larger size than the existing ferry.

However, if the future traffic demand grows more than the three-boat capacity, a new pier should be constructed to accommodate a new ferry route. The new ferry pier will be built to the south of the existing ferry pier, which is considered appropriate as a candidate location of the Alternative Route C of the bridge option. Such demand to build the new pier would also require approach road and parking area on both sides of the river.

Further traffic growth in future by the year 2035 is estimated to require up to a third pier as shown in Figure 4.3.2.

Accordingly, the Ferry Improvement Option assumes that it is only allowed to operate three ferryboats on the existing route on a regular operation basis; and if the demand grows much further, new additional two piers will have to be built to the south of the existing ferry route with the maximum capacity of three ferries per pier.

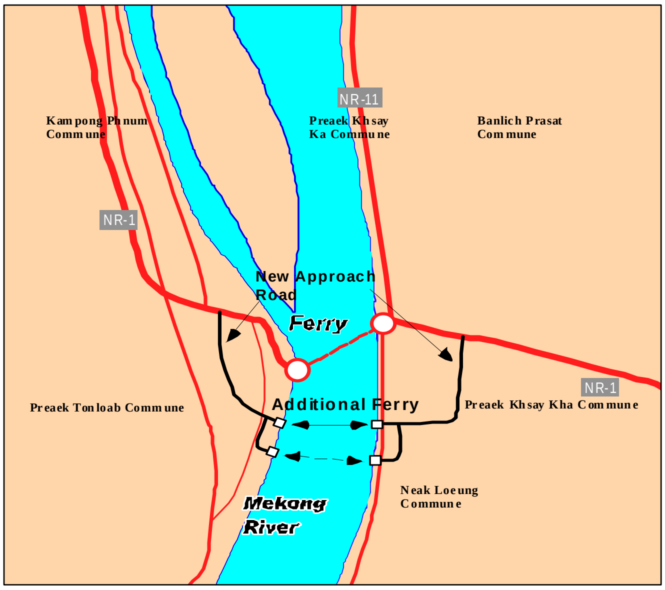


Figure 4.3.2 Possible Expansion of New Ferry Services

(Ferry Improvement Option)

3) Bridge Option

The time schedule of the "Bridge Option" is estimated to be about 5.5 years, as described below.

<u>Estimated Implementation Schedule of the Bridge Project:</u>

i) Preparatory Work .... 1 year
(including Official EIA Procedures, Basic Engineering Design, Land Acquisition and Compensation, Fund Procurement and Administration, Detailed Engineering Design)

ii) Tender Process and Contract Awarding.. ……about 0.5 years

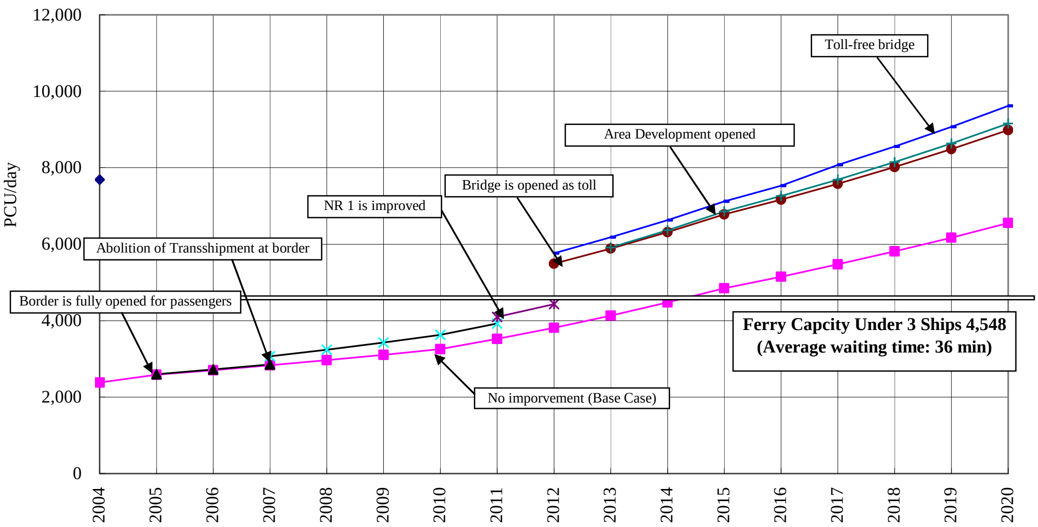
iii) Bridge Construction and Supervision .... about 4 years

4) Combined Option of Ferry Improvement and Bridge

When the analysis was undertaken in 2004 to seek for the optimum crossing method, ferry operation then was only two ferryboats. Since implementation of the bridge project is estimated to take about 6 years, the demand forecast suggests providing an additional ferry to the existing ferry route, because the traffic demand is estimated to reach the ferry capacity (2,790 PCU) in 2007. Therefore, "Ferry Improvement + Bridge" option implies to provide an additional ferryboat to the existing route before 2007 to operate until the bridge is constructed by 2012; this is the major difference between the "Bridge" option and the "Ferry Improvement + Bridge" option.

The "Ferry Improvement + Bridge" option, however, only describes the total figure of the alternative option but this does not mean that the project should consist of two components, i.e. "Ferry Improvement" sub-project and "Bridge" construction sub-project. The ferry improvement is just considered as a prerequisite.

In early 2005, MPWT deployed the additional ferryboat to the Neak Loeung Ferry Operation Unit, and therefore the operation unit has now three-ferryboats as the demand requires. As the consequence, there exists no basic difference between the "Bridge" option and the "Ferry Improvement + Bridge" option, unless the bridge construction is inevitably postponed far beyond the year 2012 when the three-ferryboat capacity reaches saturation. If such case occurs, another ferry route will be required as assumed by the "Ferry Improvement" option.



Note: Traffic demand is estimated under the assumption that GDP growth is 6 % per annum.
Source: JICA Study Team

Figure 4.3.3 Traffic Demand and Ferry Capacity (36 minutes of waiting time)

4.3.3 Evaluation of Weights on Criteria for AHP (2)

According to the questionnaire interview survey to the stakeholders, it was found that they, except for the Donor group, allocate relatively higher importance to the "Engineering Criteria" or "Economic Criteria" rather than "Environmental Criteria". Furthermore, between "Engineering Criteria" and "Economic Criteria", a higher importance depends upon stakeholder groups. A group of the government officials gives almost equal importance to both "Engineering" and "Economic" Criteria. Groups of Private Sector, Neak Loeung Ferry staff and Villagers tend to evaluate "Engineering Criteria" more important than "Economic Criteria", while groups of NGO and Research Institute appreciate "Economic Criteria" more importantly. The survey results are detailed in Appendix 4.3 and summarized in Table 4.3.2 with the following comparison among the average weights of Stakeholders (91 samples), MPWT (10 samples) and JICA Study Team (5 samples):

- "Engineering Criteria" is highly appreciated by MPWT followed by the average figure of the Stakeholders and the Study Team
- On the contrary, "Environmental Criteria" is highly rated by the Study Team followed by the average figure of the Stakeholders and MPWT.
- Among the sub-criteria of "Engineering Criteria", the average Stakeholders and MPWT show more importance to "Sustainability", while the Study Team to "Safety".
- Among the sub-criteria of "Economic Criteria", the average Stakeholders and MPWT reveal their appreciation distinctively to "Appropriateness to Traffic Demand", while the Study Team's rating is more balanced among the sub-criteria "Appropriateness to Traffic Demand", "Investment Efficiency" and "Impacts on Regional Economy".
- Regarding the sub-criteria of "Environmental Criteria", the average Stakeholders show relatively higher importance to "Natural" rather than "Social", while MPWT and the Study Team rate higher to "Social Environment".
- "Traffic Accidents" is regarded very important, compared to other sub-criteria of "Natural Environment" commonly by the average Stakeholders, MPWT and the Study Team.
- Among the sub-criteria of "Social" Environment, the Study Team distinguishes more importance of "Involuntary Resettlement" from others, but the average Stakeholders give higher rating almost equally to both "Involuntary Resettlement" and "Impacts on Land Use"; and MPWT almost equally to "Impacts on Local Livelihood" and "Involuntary Resettlement".

4.3.4 Evaluation of Alternative Crossing Methods by Criteria

The alternative crossing methods, i.e. "Zero Option", "Bridge", "Ferry Improvement", "Ferry Improvement + (and then) Bridge", are technically compared with regard to the criteria/sub-criteria, for which weights are relatively evaluated in previous section 4.3.3.

A judgment is made when comparing between a pair-wise alternative crossing methods, and so a scale of relative importance is used ranging from one to nine as defined in previous Table 4.1.4.

The Study Team discussed intensively among its members regarding the relative importance of each pair of alternatives in regard to the selected criteria. After the discussion, rating was made individually first and the results were gathered later for check and review. If a rate is found to deviate from or opposite to the team's average, the reason is explored for confirmation. If the reason is acceptable, the rate remained unchanged, but if not, it was revised or corrected.

As the consequence, individual rates given to the pair-wise alternative comparison are averaged geometrically for integration. The general background of the rating is described below in regard to the selected sub-criteria, and the resultant average ratings are tabulated in Appendix 4.3 and summarized in Table 4.3.2.

1) Regarding "Stability"

Generally, the bridge can accommodate people with more stable service to cross the river than ferry. This issue was considered when comparing between "Bridge" and "Ferry Improvement" options. There was a view that "Ferry Improvement" is superior to "Bridge", unless the bridge is completed before 2012 when the existing 3-ferryboat capacity would be over-saturated. Therefore, any delay of the bridge construction without ferry improvement will bring about the deterioration of the stable crossing services after 2012. Eventually, ratings on both views, i.e. "Bridge" and "Ferry Improvement", were accepted.

2) Regarding "Safety"

Similar to the above, there was a view that the Bridge option could not be assured, before completion of the bridge, the same level of "Safety" service as the "Ferry Improvement" option, although the bridge is superior to ferry in safety crossing service.

3) Regarding "Sustainability"

This was also rated the same as the previous two criteria.

4) Regarding "Appropriateness to Traffic Demand"

"Bridge" option alone could not cope with the increasing traffic demand especially before the bridge is completed.

5) Regarding "Investment Efficiency"

A preliminary economic evaluation was undertaken in the Interim Report stage to find the investment priority among the alternatives. The result shows that the Net Present Value is higher in the order of "Ferry Improvement + Bridge" > "Ferry Improvement" > "Bridge Only" options.

6) Regarding "Impact on Regional Economy"

The bridge at Neak Loeung is highly appreciated for its importance as part of the inter-regional and international transport services in the GMS and ASEAN region as well.

7) Regarding "Noise and Vibration"

"Zero Option" is considered to bring about more serious traffic jams at the present terminal area as the traffic grows in the future.

8) Regarding "Traffic Accidents"

The judgment is different depending upon the appreciation of traffic jam intensified at the terminal of "Zero Option" or prolonged vehicle-kilometers by the additional terminal. Both views are accepted to remain unchanged.

9) Regarding "Other Impacts on Natural Environment"

Development activities are considered to bring about additional impacts to the natural environment.

10) Regarding "Involuntary Resettlement"

The "Bridge" option assumes its location on Route-A, which requires less involuntary resettlements than Route-C, where the "Ferry Improvement" option assumes to build additional pier. Therefore, "Bridge" option causes less resettlement in number than "Ferry Improvement".

11) Regarding "Impacts on Land Use"

It is generally accepted that the bridge construction has widespread impacts on land uses not only in the neighboring areas, but also in the regional development context.

12) Regarding "Impacts on Local Livelihood"

It is considered that the "Bridge" option may cause vendors, restaurant owners/workers, and so on around the ferry terminals to lose or reduce their business opportunities, but the bridge construction, on the contrary, has a potential to develop land along the approach road where such project affected people can be absorbed in higher priority.

13) Regarding "Other Impacts on Social Environment"

It is considered that any development activities such as bridge construction and ferry improvement will bring about relatively positive impacts on other social conditions.

4.3.5 Overall Evaluation of Alternative Crossing Methods

Based on the analyses made previously in sections 4.3.3 and 4.3.4, the scale ratios (weights) derived separately from the comparison of each pair of criteria or alternatives are summarized by groups of stakeholders, MPWT and the Study Team as shown in Table 4.3.2, and are synthesized to resolve a multi-criteria decision and to best select the highest priority among alternative crossing methods of "Bridge", "Zero Option", "Ferry Improvement" and "Ferry Improvement + Bridge".

Priority scale ratios of the alternative methods are shown in Table 4.3.3 and Figure 4.3.4; they reveal, in all groups of stakeholders, MPWT and the Study Team, that the "Ferry Improvement + Bridge" option is given the highest priority (ranging 48.0%~50.5%) followed by "Bridge" (22.5%~24.6%), "Ferry Improvement" (18.8%~20.6%) and "Zero Option" (6.2%~11.0%).

Consequently, it is confirmed that all stakeholder groups as well as MPWT and the Study Team are in agreement with the "Ferry Improvement + Bridge" option on Alternative Route A as the optimum crossing method to cross the Mekong River at Neak Loeung.

Table 4.3.2 Summary of Weights on Criteria by Group and on Alternative Methods

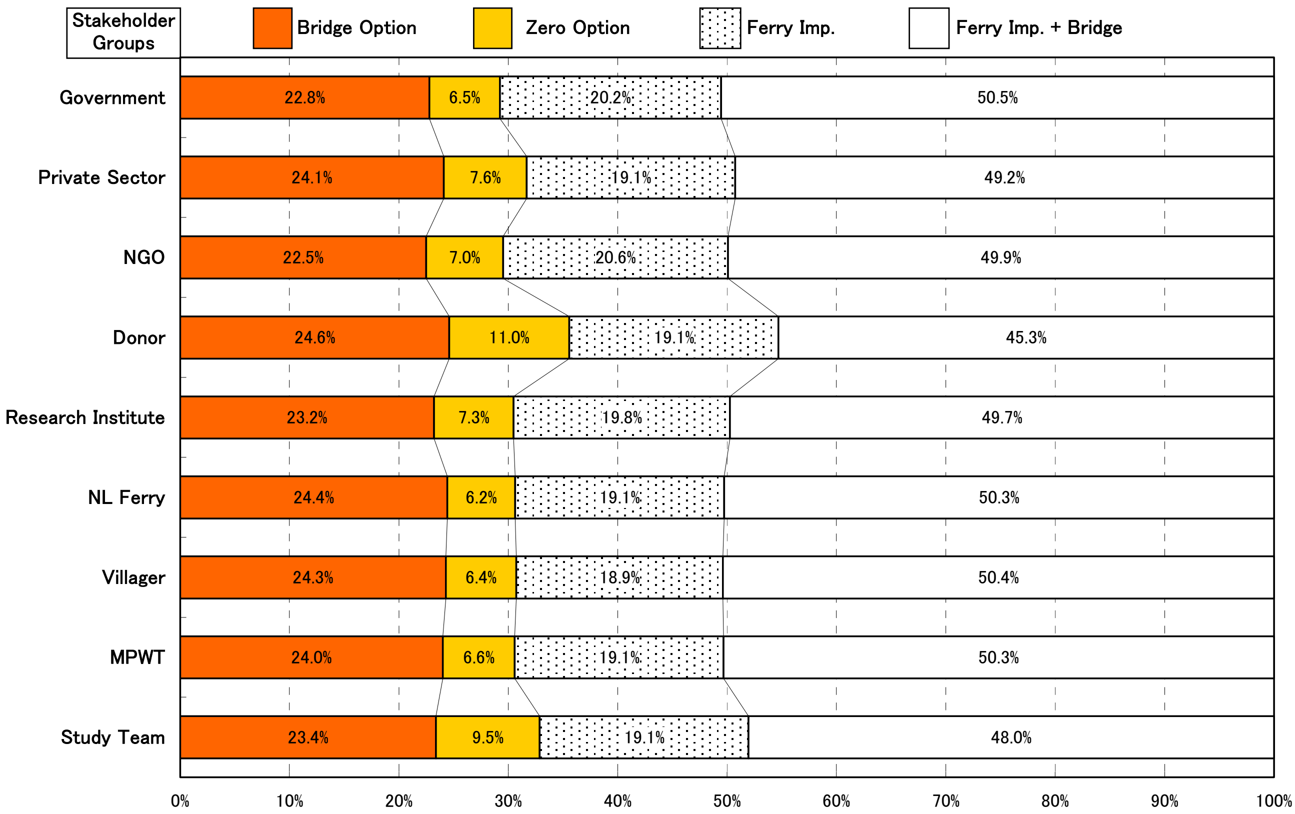
Criteria	1 Government	2 Private Sector	3 NGO	4 Donor	5 Research Institute	6 NL Ferry	7 Villager	8 MPWT	9 Study Team	Bridge	Zero Option	Ferry Imp.	Ferry + Bridge
Engineering Criteria	(0.464)	(0.491)	(0.346)	(0.177)	(0.370)	(0.561)	(0.604)	(0.610)	(0.348)				
Stability of Crossing Service	0.134	0.163	0.164	0.059	0.084	0.090	0.177	0.225	0.091	0.200	0.048	0.205	0.547
Safety of Crossing Service	0.126	0.210	0.096	0.039	0.114	0.078	0.155	0.093	0.156	0.324	0.064	0.120	0.492
Sustainability of Crossing Service	0.204	0.118	0.085	0.079	0.171	0.394	0.273	0.291	0.102	0.309	0.057	0.142	0.492
Economic Criteria	(0.470)	(0.383)	(0.547)	(0.313)	(0.543)	(0.379)	(0.331)	(0.323)	(0.466)				
Appropriateness to Traffic Demand	0.230	0.187	0.249	0.143	0.221	0.201	0.160	0.192	0.180	0.170	0.054	0.266	0.510
Investment Efficiency	0.180	0.092	0.123	0.056	0.164	0.142	0.127	0.080	0.143	0.141	0.059	0.262	0.539
Impacts on Regional Economy	0.060	0.103	0.174	0.114	0.157	0.036	0.044	0.051	0.142	0.277	0.051	0.165	0.507
Environmental Criteria	(0.066)	(0.126)	(0.107)	(0.510)	(0.087)	(0.059)	(0.065)	(0.067)	(0.186)				
Natural Environmental Criteria	(0.035)	(0.075)	(0.036)	(0.255)	(0.025)	(0.047)	(0.043)	(0.021)	(0.056)				
Noise and Vibration	0.011	0.023	0.007	0.034	0.004	0.019	0.017	0.002	0.008	0.249	0.109	0.225	0.418
Traffic Accidents	0.016	0.034	0.017	0.170	0.015	0.024	0.019	0.014	0.035	0.263	0.141	0.141	0.455
Other Impacts on Natural Environment	0.008	0.018	0.012	0.051	0.007	0.004	0.006	0.005	0.013	0.172	0.354	0.354	0.121
Social Environmental Criteria	(0.031)	(0.051)	(0.071)	(0.255)	(0.063)	(0.012)	(0.021)	(0.046)	(0.130)				
Involuntary Resettlement	0.009	0.019	0.017	0.034	0.026	0.003	0.008	0.015	0.061	0.171	0.535	0.092	0.203
Impacts on Land Use	0.010	0.011	0.014	0.103	0.012	0.005	0.008	0.009	0.021	0.332	0.067	0.111	0.491
Impacts on Local Livelihood	0.008	0.010	0.024	0.076	0.011	0.003	0.004	0.017	0.032	0.264	0.100	0.222	0.413
Other Impacts on Social Environment	0.005	0.011	0.016	0.042	0.014	0.001	0.002	0.005	0.017	0.274	0.112	0.255	0.360
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				

Source: JICA Study Team

Table 4.3.3 Overall Evaluation of Alternative Crossing Methods

Stakeholder Groups	Bridge	Zero Option	Ferry Imp.	Ferry Imp. + Bridge
Government	0.228	0.065	0.202	0.505
Private Sector	0.241	0.076	0.191	0.492
NGO	0.225	0.070	0.206	0.499
Donor	0.246	0.110	0.191	0.453
Research Institute	0.232	0.073	0.198	0.497
NL Ferry	0.244	0.062	0.191	0.503
Villager	0.243	0.064	0.189	0.504
Average of S.H	0.235	0.069	0.196	0.500
MPWT	0.240	0.066	0.191	0.503
Study Team	0.234	0.095	0.191	0.480

Source: JICA Study Team



Source: JICA Study Team

Figure 4.3.4 Overall Evaluation of Alternative Crossing Methods

4.4 Selected Optimum Crossing Route and Method

4.4.1 Recommended Optimum Crossing Route and Method

Through the analyses made in the previous sections, the study reached the following conclusions and recommendations:

1) The "Ferry Improvement + Bridge" option should be selected as the optimum solution to cross the Mekong River at Neak Loeung, based on the ratings on evaluation criteria by concerned stakeholders and as a consequence of comparative analysis by the Study Team

2) All the concerned stakeholders, as the result of their ratings on the evaluation criteria, came to the conclusion that the "Ferry Improvement + Bridge" option is the highest priority among the alternative crossing methods, and it is justifiable from engineering, economic and environmental aspects.

3) Since it is assumed that the bridge construction will take about 6 years, including pre-construction and construction period, it is necessary to increase the existing ferry capacity (i.e. substituting one 24-pcu capacity boat for a 30-pcu capacity boat) if the bridge is not completed by the year 2012.

4) Eventually, it was concluded through consensus among stakeholders by the Public Consultation Process, that the study on the "Ferry Improvement + Bridge" option should be pursued and elaborated in the subsequent feasibility study stage.

4.4.2 Achieving Stakeholder Consensus on Project Implementation

(1) New JICA Guideline for Environmental and Social Considerations

JICA completed the new guidelines in March 2004. In accordance with this guideline, JICA encourages the recipient governments by conducting cooperation activities to implement proper measures for environmental and social considerations. In the guidelines, it is emphasized that democratic decision-making is essential for environmental and social considerations, and in order to achieve an appropriate decision-making process, it is critical to ensure stakeholder participation, information disclosure, transparency of the decision making process, accountability and efficiency as well as the respect for human rights.

The guideline urges recipient governments to consult with local stakeholders through means that encourage reasonably broad public participation, in order to consider environmental and social factors in the way that is most suitable to local situations and to reach an optimum consensus.

(2) Rationale and Approach to Achieve Stakeholder Consensus

Stakeholder consensus is the foundation upon which transparent decision-making process rests. Strategic Environmental Assessment (SEA), which underlies the New JICA Guideline, reinforces the importance of accountability to society on how environmental impacts are considered in the decision making process even at such an early stage of project implementation as policy or plan formation.

Achieving consensus does not necessarily imply collecting agreements signed by all the stakeholders, but instead is represented by a series of steps seen as being necessary to assure transparency and accountability within the decision making process. These steps rely on such institutional means as public involvement and information disclosure.

Accordingly, it is assumed that stakeholder consensus is achieved by the satisfactory integration of public involvement and information disclosure within the framework of the decision-making process leading to the selection of an optimum crossing of the Mekong River at Neak Loeung.

In order to achieve such stakeholder consensus, it is considered imperative that the following steps be undertaken:

- 1st step: Preparation of *Draft Interim Report* in which the conclusion and process of selecting the optimum solution for crossing the River are professionally and comprehensively described.
- 2nd step: Submission of *Draft Interim Report* to JICA and the MPWT
- 3rd step: Explanation and discussion of *Draft Interim Report* at JICA Advisory Committee Meeting in Tokyo
- 4th step: Finalization of *Draft Interim Report* and printing for official submission to the MPWT
- 5th step: Explanation and discussion of *Interim Report* at Steering Committee Meeting in Phnom Penh
- 6th step: Explanation and discussion of *Interim Report* at Stakeholder Meeting 2-3, which is held separately in Phnom Penh and Neak Loeung as part of public involvement and information disclosure processes.
- 7th step: At the stakeholder meetings, a closing date and places to receive additional questions and comments are announced. A one-month period for public review is fixed during the last stakeholder meeting of the Phase-1 Study. Additional questions

and comments are welcome at relevant local commune offices, the MPWT office and the web site designed especially for the Study.

- 8th step: The MPWT counterparts address these questions and comments in collaboration and communication with the Study Team. All the records including responses are filed for circulation among the stakeholders and for public information disclosure.
- 9th step: Following completion of these procedures and processes, the MPWT shall make a final decision regarding the optimum solution for crossing the River.
- 10th step: The final decision by the MPWT on the optimum solution to cross the River and records of the public consultation, (which include the minutes of the stakeholder meetings and the filing of additional questions and comments from the public, and responses by the MPWT), are all compiled and circulated through the commune offices for public reading.
- Concluding step: Successful completion of the previous ten steps confirms that the general public supports and verifies the decisions made by the MPWT, and that the Study Team may proceed with the next feasibility study stage.

(3) Announcement of Final Consensus on the Optimum Crossing Solution (Stakeholder Meeting 2-3, March 2005)

The Stakeholder Meeting 2-3 which was the last stakeholder meeting of the Phase-1 Study was held on March 10-11, 2005 in an attempt to demonstrate that the *"Ferry Improvement + Bridge (Route A)"* option was selected as the optimum solution to cross the Mekong River at Neak Loeung.

In order to further guarantee the far-reaching transparency and information disclosure to all the stakeholders, one-and-half month public comment period was set up after the Stakeholder Meeting 2-3, and, during this public comment period, MPWT received a wide range of comments and questions from 22 various stakeholders. After this public comment process, MPWT officially announced that *"Ferry Improvement + Bridge (Route A)"* option was agreed among all the stakeholders, which could be regarded as the final consensus on the optimum solution to cross the Mekong River at Neak Loeung.

4.5 Appropriate Ferry Development

4.5.1 Current Conditions of Ferry Operation in Cambodia

(1) Existing Organization and Deployment of Ferry

A significant amount of inland transportation in Cambodia relies on crossing rivers. Owing to the geographical features, ferrying service is understandably one of the most important basic services for the Cambodian people and economy.

The Ministry of Public Works and Transportation has responsibility for ferrying services crossing rivers in Cambodia. Ferry operations in Cambodia are administrated by the Department of Roads and Bridges, the Ministry of Public Works and Transportation. Organization of the Ministry of Public Works and Transportation is presented in Figure 4.5.1.

Semi-autonomous Ferry Units at Neak Loeung, Preak Kdam and Kampong Cham were established in 1985 to operate ferryboats. After completion of KIZUNA Bridge, the Kampong Cham Ferry unit closed down and its activity moved to the Preak Tamak Ferry Unit. In April, 2005, the Preak Tamak Ferry Unit was a branch unit of the Neak Loeung Ferry Unit. As of May 2005, the two (2) semi-autonomous Ferry Units, the Neak Loeung

Ferry Unit and the Preak Kdam Ferry Unit under the Department of Roads and Bridges, were operating the major ferryboats crossing the Mekong River at Neak Loeung and Preak Tamak and Tonle Sap River at Preak Kdam.

In addition, the Department of Roads and Bridges is directly operating a ferry barge crossing the Mekong River and Sekong River at Stung Treng. The main tasks and activities of these ferry units are:

- To provide and maintain ferrying services, channels and navigation systems
- To manage and operate ferry facilities and equipment
- To manage workshop for maintenance service

River Waterway Plan for 4 year periods 2004-2008 in "WORK PROGRAM AND PLANNING ACTIVITY (2004-2008) made by the Ministry of Public Works and Transportation in August 2004" includes:

- Support the establishment of crew training school and mechanic
- Support the construction of constructing and domestic repairing workshop

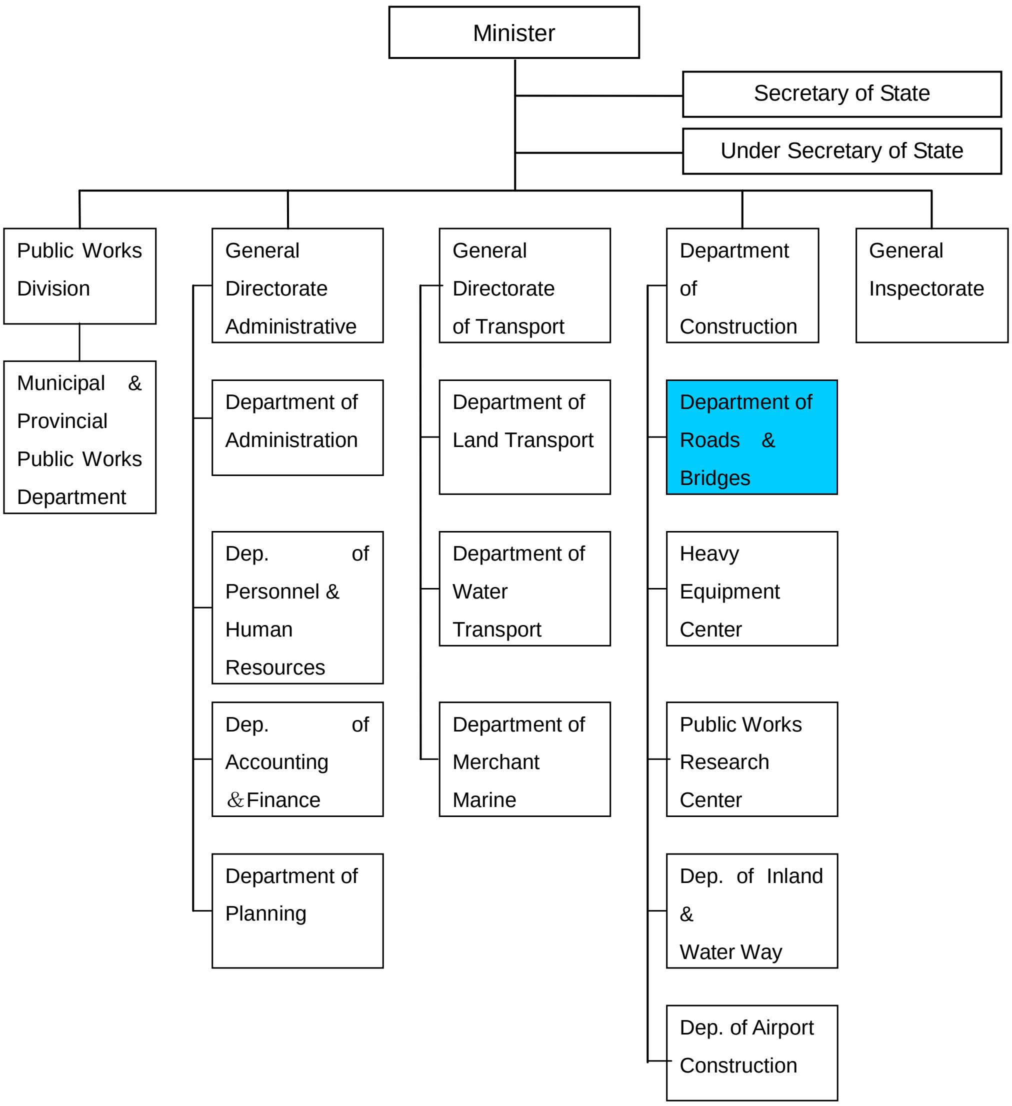


Figure 4.5.1 Organization Chart of the Ministry of Public Works and Transportation

The current number of major ferryboats operating for crossing rivers in Cambodia is six (6) at four (4) locations of ferrying service as shown in Table 4.5.1 and Figure 4.5.2.

Table 4.5.1 Current Deployment of Major Ferryboats in May 2005

Location	Name of Ferry	Type of Ferry	Year of built and place
Neak Loeung	TA PHROM	Double ended Ferry	1997 Feb.15 in Cambodia
Neak Loeung	VISHNU	Double ended Ferry	1997 Dec.17 in Cambodia
Neak Loeung	PEACE-2	Double ended Ferry	1991 in Hong Kong 1998 Apr.30 (rehabilitated)
Preak Tamat	SAMAKI-27	Double ended Ferry	1981 in Singapore 1999 Oct.8 (rehabilitated)
Preak Kdam	SAMAKI-28	Double ended Ferry	1981 in Singapore 1999 Feb.24 (rehabilitated)
Stung Treng	STUNG TRENG	Double ended Barge	Unknown 2000 (Shifted from Phnom Penh)

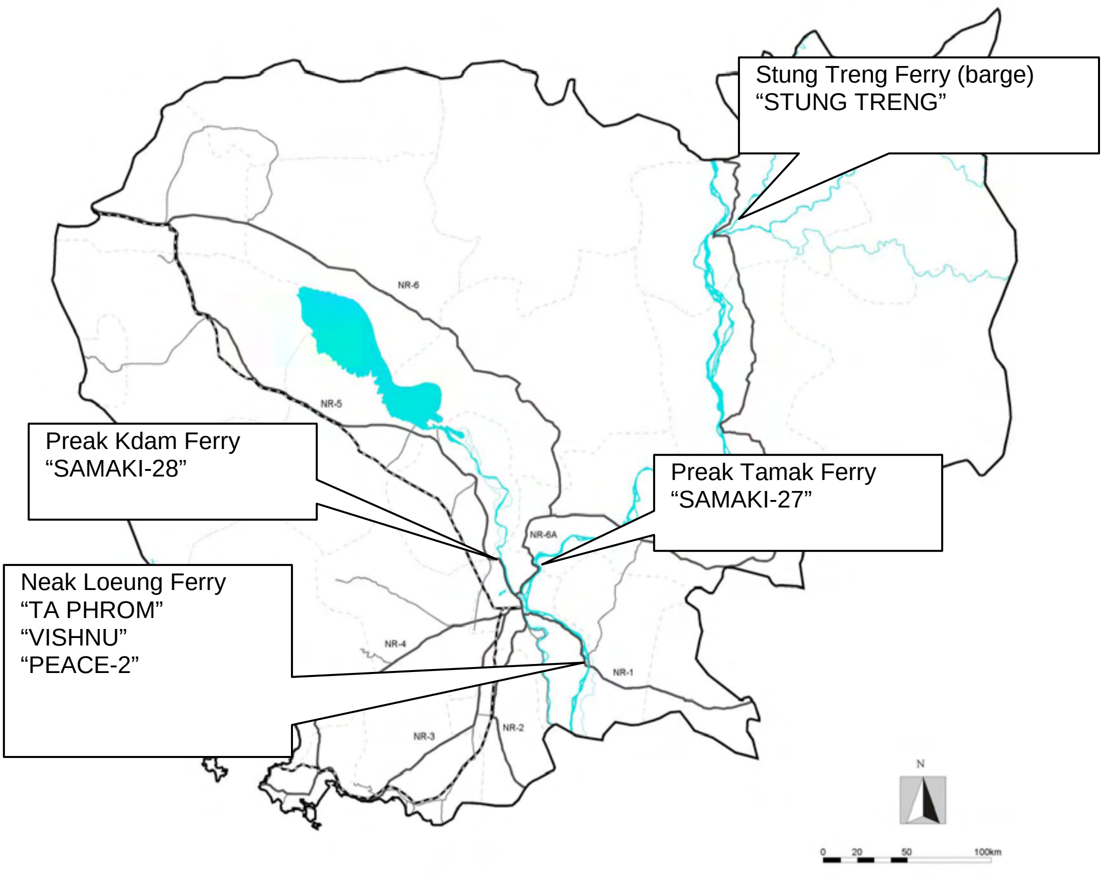


Figure 4.5.2 Map of Ferryboat Deployment

Existing ferry services at each operation route are described in more detail in Appendix 4.5.

(2) Evaluation of Existing Ferryboats and Recommendations

The ferryboat "PEACE-2" was built in 1991 and rehabilitated in 1998 including the replacement of engines and propellers. The ferryboats "SAMAKI-27" and "SAMAKI-28" were built in 1981 and rehabilitated in 1998 including the replacement of the engines and the propellers. Since the periods between new building and rehabilitation including the replacement of the engines and the propellers for these ferryboats was very short, it is supposed to be caused by a lack of proper maintenance and repair. The existing ferryboats at Neak Loeung are maintained; however, quality of repair and maintenance seems to be low since a recent Neak Loeung statistic shows that the repairing expense for ferryboats is decreasing year to year regardless of increasing need of repair as the years pass. Other ferryboats at Preak Tanak, Preak Kdam and Stung Treng need urgent docking repair and maintenance, otherwise, serious trouble will be happened on these ferryboats.

Through the evaluation of the existing conditions of the ferryboats at the four (4) ferry units, recommendations, in order to operate the existing ferryboats safely, reliably and economically, are made as follows:

1) Maintenance and repair schedule including budgeting shall be established.

    a) Periodic maintenance and docking repair shall be carried out on schedule.
    b) Preventive maintenance shall be carried out.

2) Periodic inspection shall be done by Classification Society or the third party

3) Continuous training and education program for crew shall be implemented

4) Complete technical documents shall be clearly filed and kept at office and on board.

5) Performance data of engines and other machineries shall be recorded, analyzed and filed daily.

4.5.2 Ferryboat Rehabilitation and New Building Project Financed by Denmark

(1) General

It was reported that The Royal Government of Denmark signed a financing agreement for US$ 18 million in May 1995 with the Mekong River Commission (MRC) for financial support to the project “Upgrading of Ferry Facilities in Cambodia”.

The project comprises three major activities:

- Construction of two (2) new ferry boats and rehabilitation of three (3) ferry boats for services at Neak Leung, Kompong Cham, and Prek Kdam Ferry Terminals.
- Improvement of the landing facilities including a slipway for ship repairs and new buildings.
- Training and capacity building of Cambodian staff at the Ferry Units.

(2) Implementation Scheme of the Project

The Mekong River Commissions made a contract with contractors in Denmark for package supply and also made a contract with contractors in Cambodia for works. Contract scheme and the contents of the Contracts are described in Figure 4.5.3.

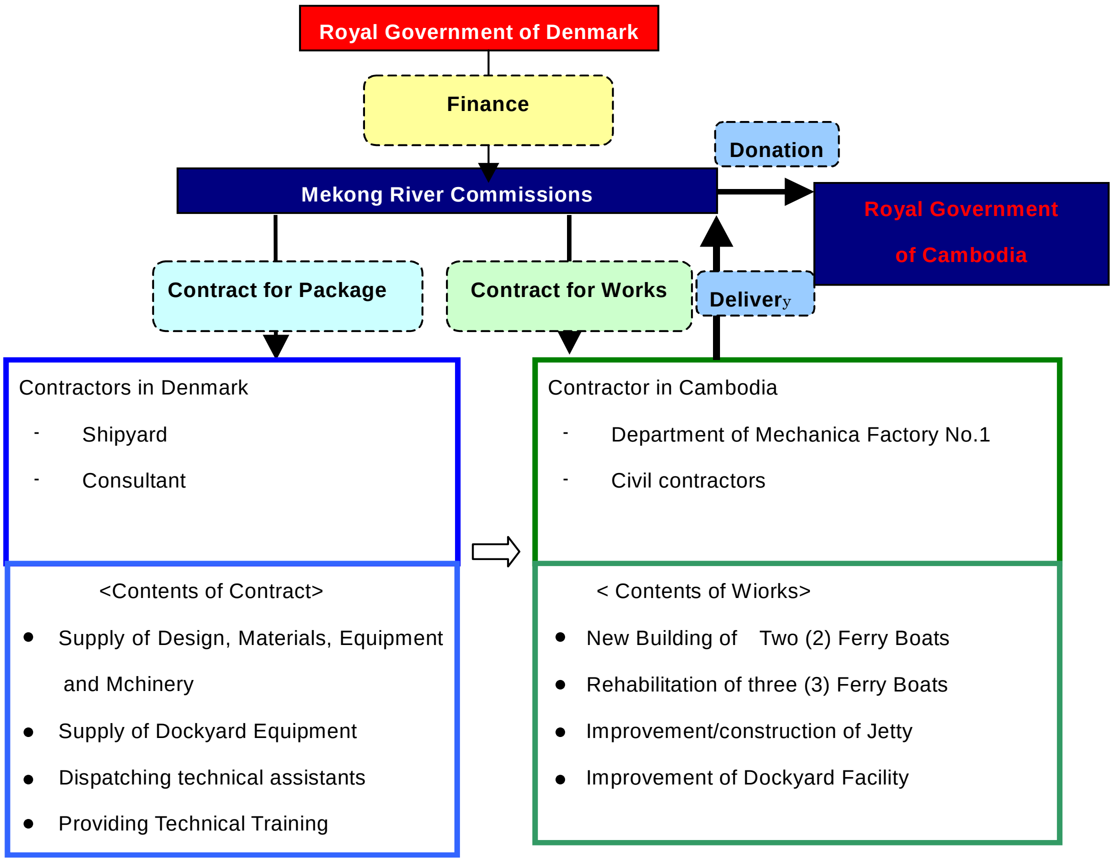


Figure 4.5.3 Implementation Scheme

(3) New Building and Rehabilitation of Ferries and Associated Facilities

The five ferries were completed at the Department of Mechanical Factory No.1 in Phnom Penh and handed over to the Government of Cambodia as follows:

- The newly-built ferry boat "Ta Prohm" was handed over on 15 February 1997 for the operation at Neak Leung.
- The second newly-built ferry boat "Vishnu" was handed over on 17 December 1997 to Kampong Cham, and it is now in service at Neak Loeung.
- The first rehabilitated ferry boat "Peace 2" was handed over on 30 April 1998, and it is now in service at Neak Leung.
- The second rehabilitated ferry "Samaki 27" was handed over on 8 October 1998 to Kampong Cham, and it is now in service at Preak Tamak.
- The third rehabilitated ferry boat "Samaki 28" was handed over on 24 February 1999 to service at Prek Kdam.
- The landing facilities at Neak Leung have been reconstructed according to the civil works program, and two (2) hard wood jetties were built at Prek Kdam to facilitate the operation of ferry boats at these river crossings.
- A fully operational shipyard at Neak Leung, and adequate workshop facilities have been established at the three (3) ferry stations, for service and minor repairs of all vessels under the Ministry of Public Works and Transportation (MPWT).

- The MPWT staff has been trained for shipbuilding technology to execute at least all type of essential repairs. The work undertaken by the contractors was prepared, supervised and executed with full participation of the MPWT and the Ferry Unit at Neak Leung, Kompong Cham and Prek Kdam. Throughout the construction, Cambodian professional staff and welders were trained and new construction methods in shipbuilding were applied as "On Job Training".

(4) Current Conditions of Shipyard Facility

1) Department of Mechanical Factory No.1

After the work of the project in 1999, shown in Appendix 4.5, the Department of Mechanical Factory No. 1 terminated its activity of shipbuilding and repair. At present, its facilities and land have been leased to private company as shown in Figure 4.5.4.

Figure 4.5.4 Department of Mechanical Factory No.1 in Phnom Penh

2) Dockyard at Neak Loeung

Dockyard at Neak Loeung has been established and for repair and maintenance of ferry boats as well as ships owned by other Departments and private commercial boats. Total staff and workers for Dockyard at Neak Loeung are five (5). Slipway with a length of 132 m was constructed and 450 tons capacity of towing winch is available for docking of present ferryboats.

New building at Dockyard at Neak Loeung is supposed to be quite difficult in terms of factory arrangement and space, facilities, equipment and number and skills of workers. The layout of the Neak Loeung Dockyard is shown in Appendix 4.5.

4.5.3 New Building of 30 PCU Ferryboat

(1) Site Condition for Ferry Operation

As described in Section 5.2 Natural Conditions of the Interim Report (March 2005), the sites of ferry operation are located to cross the Mekong River, the Tonle Sap River and the Kong River, and are covered by tropical monsoon conditions. According to the Interim Report, wind velocity, velocity of water flow and water level are as follows:

1) Wind Velocity

Maximum wind velocity in the past 10 years in 1985-1995 is 28m/s, and 14m/s in 2001-2003, however, in general wind velocity is gentle and rarely excess of Beaufort 5-6.

2) Velocity of Water Flow

Maximum velocity of water flow of the river is 1.96 m/s (3.8 knots) at Neak Loeung.

According to the study on Hydro-Meteorological Monitoring for Water Quantity Rules in MRB, maximum velocity at the time of flood is 1.6 m/s (3.1 knots) and minimum flow velocity is 0.5 m/s (1.0 knots).

3) Water Level

There are big seasonal fluctuations in water level of the Mekong River. The high water period last from September to November and the low water period last from February to April. At Neak Loeung Gauging Station, the highest water level fluctuates greatly in each year from 6 to 8 m above MSL. The maximum difference between the highest and the lowest water level is 6.5m. By Figure 5.2.1 of Interim Report, the maximum difference between the highest and lowest water level at Kompong Cham is approx. 13 m.

4) Water Depth

Minimum water depth in five (5) ferry operation routes, Neak Loeung (Mekong River), Preak Tamak (Mekong river), Preak Kdam (Sem river), Stung Treng (Sekong river & Mekong river), is approx. 4 m at low water season.

5) Site Conditions

Air Temperature	: 40ºC
Relative humidity	: 95%
River water temperature	: 35ºC
Air pressure	: 760 mmHG / 1,013 mbar

(2) Design Conditions

New ferry boat shall be appropriately designed for both Neak Loeung ferrying service and other ferrying service routes, based on site conditions described in the previous section and the following requirements:

1) Loading capacity shall be 30 PCU at least
2) Ferry’s speed shall be same as the present ferry boats
3) Length of each ramp at stem and stern shall be 10 meters for beach landing operation due to geographical features of bank for ferrying service at river
4) High maneuverability suitable for operation in the Mekong River shall be assured.

(3) Particulars and General Arrangement of Appropriately Designed Ferry boat

An outline and general arrangements of the 30 PCU ferryboat are presented in Table 4.5.2 and Figure 4.5.5, respectively.

Table 4.5.2 Outline of 30PCT Ferryboat

Type of Ferry	Double ended ferryboat
Classification Society	International classification Society
Length overall including ramps	69.5 m
Length of deck	49.5 m
Breadth moulded	11.5 m
Breadth including fenders	11.9 m
Depth moulded	2.4 m
Draft (designed)	1.5 m
Deadweight	220 tons
Passenger car unit	Sedan (5.5m x 1.8m) x 30 units
Truck	Truck (12m x 2.5m) x 12 units
Main engines	320 KW x 2 units
Fuel oil tank	20 m3
Lubricating oil tank	0.5 m3
Fresh water tank	15 m3
Waste oil tank	1.0 m3
Propellers	Rudder propeller x 2 units
Speed	8 knots

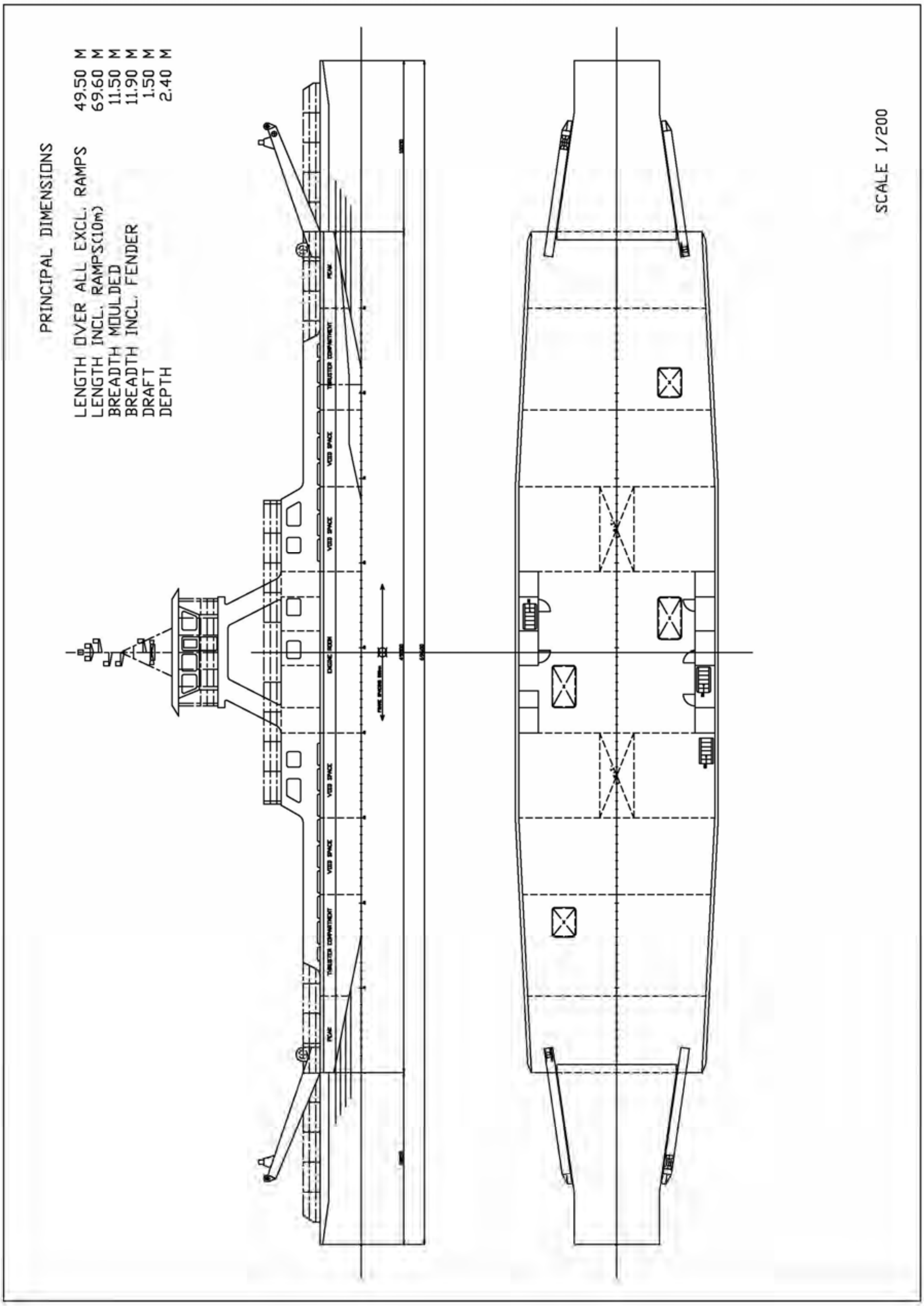


Figure 4.5.5 General Arrangement of 30 PCU Ferryboat

(4) Construction Scheme, Schedule and Acquisition Cost

1) Construction Scheme and Schedule

Ferryboat "TA PHROM" and "VISHNU" were built at the Department of Mechanical Factory No.1 under the project of "Upgrading of Ferry Facilities in Cambodia" financially supported by MRC. Adding to the new building, the project included rehabilitation works of another three ferryboats and training and capacity building of Cambodian staff. During the project, shipbuilding experts and consultant from Denmark stayed at DMF No.1 and assisted for the whole works of the project.

The same as the above project, the construction of new ferryboat in Cambodia may contribute to development and improvement of shipbuilding and repair technology in Cambodia which will be transferred from foreign experts during construction period same as above project. However, as mentioned in 6.2.3, DMF No.1 is no more active for new shipbuilding or repair works since DMF No.1 was closed down after the above project.

The Neak Loeung Dockyard is active but not suitably accommodated for new building in terms of insufficient facilities and equipment, lack of engineering capability and a limited period of slipway availability due to rainy season. In addition, the slipway will not be used for docking repair/maintenance for the existing ferryboats if a new construction occupies the slipway.

Thus, the construction scheme and schedule were prepared, based on the building at shipyard in Japan. It will take around 10 months to construct, deliver a ferryboat at shipyard in Japan and to take over at Neak Loeung Ferry Unit. The construction schedule is shown in Figure 4.5.6.

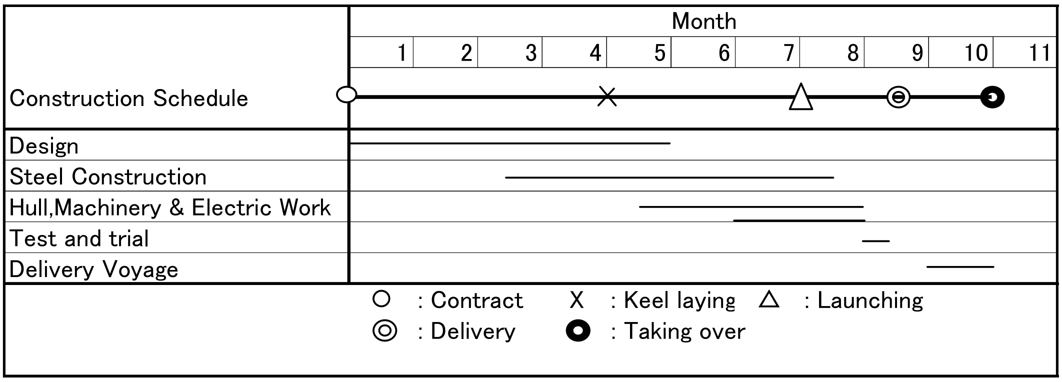


Figure 4.5.6 Construction Schedule

2) Acquisition Cost

Based on the particulars and general arrangement of the planned 30 PCU ferryboat, the acquisition cost, when built in Japan, will be approximately US$3.5 million in 2005 prices as shown in Table 4.5.3.

Table 4.5.3 Acquisition Cost of 30 PCT Ferryboat

Item	Cost (US$)
Materials, Equipment & Materials	1,600,000
Direct & Indirect	1,000,000
Design	150,000
Administration and General expense	750,000
Total Acquisition Cost	3,500,000

4.5.4 New Deployment Planning of Ferryboats after Completion of Bridge

(1) Existing Deployment Plan by Cambodian Government

The Department of Road and Bridge, MPWT is planning a new development of ferrying services crossing the Mekong River, the Tonle Sap River and the Bassac River. The new deployment plan of ferryboats is derived from the Ring Roads Plan in Phnom Penh and reinforcement of the existing ferrying services as follows:

1) Two (2) ferryboats shall be deployed for development a new ferrying service crossing the Bassac River at Ta Khmau to the south of Monyvong Bridge in order to alleviate traffic congestion at Monyvong Bridge.
2) Two (2) ferryboats shall be deployed for development a new ferrying service crossing the Tonle Sap River at Preak Phnom to the north of Phnom Penh City to link Road No. 5 with Road No. 6A.
3) One (1) ferryboat shall be added to reinforce ferrying service at Preak Kdam.
4) Two (2) ferryboats shall be deployed at Stung Treng and replace the present ferry barge and tug boat for safety and efficient operation for crossing the Mekong River.

In this study, a New Deployment Plan of Ferryboats is based on the following conditions:

- To improve existing ferrying services.
- To consider new deployment plan by Cambodian Government as described above.
- When a new ferryboat is deployed, existing old ferryboats should phase out sequentially as a replacement.

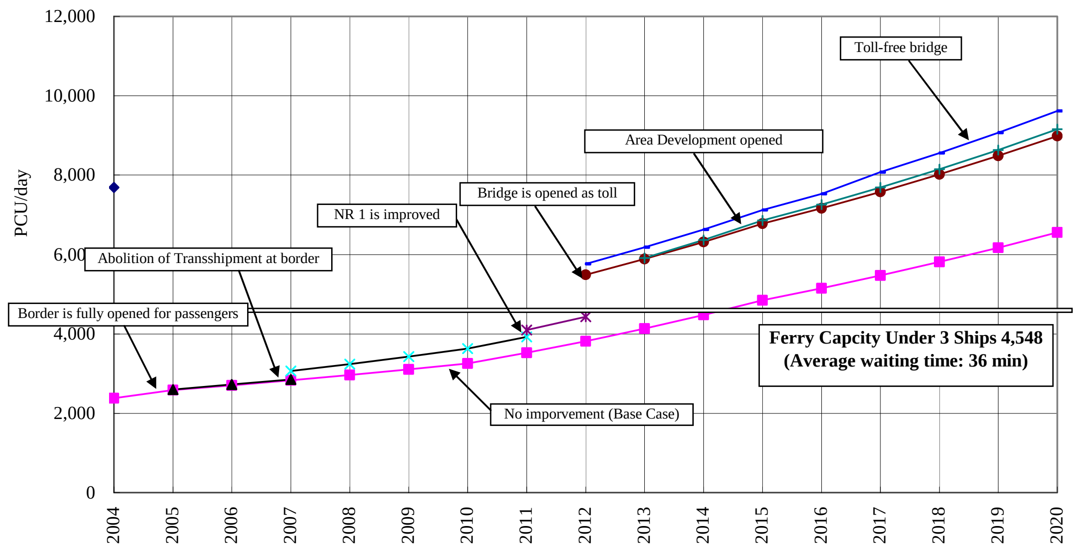
(2) Existing Ferryboat Deployment (Total six (6) ferryboats)

Currently, six (6) ferryboats are deployed at four (4) major ferry terminals along the Mekong River and the Tonle Sap River in August 2005. The capacity and age of the existing ferryboats are shown in Table 4.5.4.

Table 4.5.4 Age of Ferryboat

Name of Ferryboat	No. of PCU	Year of Built	Year of Rehabilitation	Age in 2014 from the year of built	Age in 2014 from the year of rehabilitated
TA PHROM	24	1997	-	17	-
VISHNU	24	1997	-	17	-
PEACE-2	24	1991	1999	23	15
SAMAKI-27	13	1981	1999	33	15
SAMAKI-28	13	1981	1999	33	15
STUNG TRENG	8	n/a	n/a	n/a	n/a
"UNICEF-2"(tugboat)	n/a	1981	n/a	33	n/a

According to the traffic demand forecast of the Neak Loeung Ferry, the present ferrying service by three (3) ferryboats with 24 PCU capacity each will be able to accommodate the future traffic demand of the Neak Loeung Ferry until 2012 as shown in Figure 4.5.7.



Note: Traffic demand is estimated under the assumption that GDP growth is 6 % per annum.
Source: JICA Study Team

Figure 4.5.7 Ferry Capacity and Forecast Traffic Demand of Neak Loeung Crossing

Thus, the present deployment of ferryboats shall be maintained until 2012 as shown in Table 4.5.5.

Table 4.5.5 Deployment Plan of the Existing Six (6) Ferryboats (2005-2012)

	Neak Loeung	Preak Tamak	Preak Kdam	Stung Treng
2005 - 2012	3	1	1	1
TA PHROM	●			
VISHNU	●			
PEACE-2	●			
SAMAKI-27		●		
SAMAKI-28			●	
STUNG TRENG＋ “UNICEF-2”(tugboat)				●

(3) New Ferryboat Deployment after 2012 (Case-I and Case-II)

<u>Year 2012-2014</u>

In 2012, Neak Loeung Ferry Unit needs to increase the existing ferrying capacity that presently consists of three (3) ferryboats of 24 PCU, by replacing one (1) ferryboat with such a higher capacity boat as 30 PCU ferry, unless the project bridge is completed by that time.

If the new 30 PCU ferry is deployed for Neak Loeung Ferry Unit, seven (7) ferryboats in total will become available in Cambodia as shown in Table 4.5.6. A 4-ferryboat operation system at Neak Loeung is theoretically possible but practically difficult for reasons such as a lack of sense in punctual operation and maintenance management. Further, the 4-ferryboat operation requires additional facility expansion, like a pier, and operation costs.

Therefore, it is recommended that one (1) 24 PCU capacity ferryboat at Neak Loeung should be replaced by the 30 PCU ferry, and the former ferryboat be deployed either for another high-demand route, or as substitution for repair, or as an addition for emergency to other ferrying service units. Since only a ferry barge is deployed for “STUNG TRENG” it might be replaced with a ferryboat in the occasion to reinforce the Neak Loeung Ferry as shown in Table 4.5.6.

Based on the future traffic demand forecast for the Neak Loeung crossing, the operation system consisting of two (2) 24 PCU ferryboats and one (1) 30 PCU ferryboat will accommodate the traffic demand by 2014, unless the project bridge is constructed beforehand.

Table 4.5.6 Deployment Plan of Existing (6) and Additional One (1) 30PCU Ferryboat (2012-2014)

No of ferryboats		Neak Loeung	Preak Tamak	Preak Kdam	Stung Treng	Ta Khmau	Preak Phnom
Existing 6 ferryboats + Additional I (30 PCU) ferryboat	2012-2014	3	2(1)	1	1(2)	n/a	n/a
	TA PHROM	●					
	VISHNU	●					
	30 PCU	●					
	PEACE-2	○ ──►	●				
	SAMAKI-27		● ·········►		(●)		
	SAMAKI-28			●			
	*STUNG TRENG				● or (X) (abandoned)		

After year 2014 (after opening of the Bridge)

After the project bridge is open to traffic, the ferry system at Neak Loeung will be abandoned and three ferryboats will be deployed to other ferry terminals. Since there are many possibilities but uncertainties either for the future ferry development, several development scenarios were explored, based on such major assumptions as follows:

1) Since ages of the existing ferryboats will be more than 33 years in 2014 at ferry terminals other than Neak Loeung, unused ferryboats from Neak Loeung should be deployed for the present remaining terminals, i.e. Preak Taamak, Preak Kdam and Stung Treg. Two ferryboats are the minimum requirement to assure continuous ferry services.

2) Since new ferry terminals are planned at Ta Khmau and Preak Phnom, two boats out of the three at Neak Loeung should be deployed for them. The remaining one boat should be reserved for a high demand route or as substitution for such a need as docking for repair or as an addition required for a sporadic high traffic demand at any of the terminals. Proper maintenance of the existing ferryboats is an essential condition to realize this scenario.

In any event, the potential demand for ferry transport in Cambodia is evident along such large rivers as the Mekong River, the Tonle Sap River and Bassac River which lie in the center of the country. The most representative cases of the above scenarios are presented in Tables 4.5.7 and 4.5.8.

Table 4.5.7 Scenario (1): Deployment of Seven (7) Ferryboats to the Existing Three Ferry Terminals after Completion of the Bridge

Name of Ferry	Neak Loeung	Preak Tamak	Preak Kdam	Stung Treng	Ta Khmau	Preak Phnom
TA PHROM	○ →	→	●			
VISHNU	○ →	●				
PEACE-2		●				
SAMAKI-27		○ →	→	●		
SAMAKI-28			○ →	●		
STUNG TRENG				**X**		
NL-NEW-1	○ →	→	●			
New deployment of ferryboats	--------	VISHNU PEACE-2	TA PHROM NL-NEW-1	SAMAKI-27 SAMAKI-28	n/a	n/a

“x” means abandonment

Table 4.5.8 Scenario (2): Deployment of Seven (7) Ferryboats to the Existing and Planned Ferry Terminals after Completion of the Bridge

Name of Ferry	Neak Loeung	Preak Tamak	Preak Kdam	Stung Treng	Ta Khmau	Preak Phnom
TA PHROM	○ →	→	→	→	●	
VISHNU	○ →	●				
PEACE-2		● →	→	→	→	●
SAMAKI-27		○ →	→	●		
SAMAKI-28			●			
STUNG TRENG				X		
NL-NEW-1	○ ⋯→	⋯→	⋯→	⋯→	●	
New deployment of ferryboats	--------	VISHNU	SAMAKI-28	SAMAKI-27	TA PHROM NL-NEW-1	PEACE-2

(4) Conclusions and Recommendations

At Neak Loeung ferrying terminals, due to the geographical features at both west and east terminals as well as navigation route in the river, maximum three (3) ferryboats in total are allowed to operate in terms of safety operation and limited terminal facilities. In April 2005, the Neak Loeung Ferry Unit was managing four (4) ferryboats: namely, three (3) at Neak Loeung and one (1) at Preak Tamak.

In order to meet the estimated future traffic demand, the existing three (3) ferryboats, “TA PHROM”, “VISHNU” and “PEACE-2” shall be fully operational at Neak Loeung until the demand will reach their transport capacity in 2012.

If the project bridge is not constructed by 2012 or not allowed to lower the ferry service quality, such as much longer queuing time over 40 minutes, the ferrying capacity shall be enhanced, for instance, replacing one (1) ferryboat of 24 PCU with a new ferryboat of 30 PCU. The study of a newly built 30 PCU ferryboat is described in previous Section 6.3.

After completion of the bridge at Neak Loeung, the existing ferryboats will be redeployed for the existing ferrying service routes as well as those prospectively developed routes, i.e. Ta Khmau and Preak Phnom which are nominated in the Government Development Plan. In addition, the ferrying service at Stung Treng also needs at least one (1) ferryboat for replacing the present ferry barge “STUNG TRENG” which may have difficulty in maneuverability for crossing the Mekong River.

In principle, appropriate number of ferryboats shall be deployed for ferrying services depending on the traffic demand, and at least two (2) ferryboats shall be deployed at one (1) ferrying service route for the sake of continuous ferrying service to cross the river, in case one (1) ferryboat is in trouble. This is not because the traffic demand needs additional capacity to two (2) ferryboats.

Acquisition of new ferryboats to replacement the existing ferryboats urgently needs to be planned, since the existing ferryboats are so old that a degradation of the boat will be accelerated year by year.

In order to enhance the ferrying service over the existing and prospective routes to cross the Mekong River or to meet the increasing traffic demand in future, recommendations are made as follows:

1) To plan a whole repair and maintenance schedule for the existing ferryboats.
2) To reserve a budget for maintenance and repair.
3) To carry out repair and maintenance of ferryboats on schedule.
4) To reinforce the workshop for improvement of quality in repair and maintenance including training and education of staff.
5) To prepare a long term deployment plan including acquisition plan of ferryboats crossing rivers in Cambodia. and
6) To expand the activity of the work at the Neak Loeung Dockyard.

CHAPTER 5

PRELIMINARY DESIGN OF ROAD AND BRIDGE

5. PRELIMINARY DESIGN OF ROAD AND BRIDGE

5.1 Highway Design Criteria and Standards

5.1.1 Review of Road Standards

This section reviews road standards and recent practices in Cambodia. Table 5.1.1 compares major design elements practiced in the road improvement/rehabilitation projects along Asian Highway Route No. 1 (AH-1) in Cambodia.

Table 5.1.1 Major Design Elements Practiced

National Road No.		1		5		
Section		Phnom Penh ~ Neak Loueng	Neak Loueng ~ Vietnam Border	Krakor ~ Svay Doun Keo	Svay Doun Keo ~ Battambang	Battambang ~ Sisophon
Length		55km	105km	80km	50km	83km
Fund Source		-	ADB	ADB	ADB	ADB
Number of Lane		2 or 4	2	2	2	2
Design Speed		80km/h	100km/h	60km/h	60km/h	60km/h
Lane Width		3.50m	3.75m	3.50m	3.50m	3.50m
Motorbike Lane Width		2.50m	-	-	-	-
Shoulder Width	Hard Type	-	1.50m	1.50m	1.50m	1.50m
	Soft Type	1.00m	0.50m	0.50m	0.50m	0.50m
Foot-path		2.50m	-	-	-	-
Cross-fall for Pavement		3.00%	3.00%	N.A.	N.A.	N.A.
Cross-fall for Soft Shoulder		4.00%	6.00%	N.A.	N.A.	N.A.
Min. Horizontal Curve		280m	500m	N.A.	N.A.	N.A.
Ma. Vertical Grade		4.00%	N.A.	N.A.	N.A.	N.A.
Type of Pavement		AC	DBST	DBST	DBST	DBST

Note: Basic Design in the section from Phnom Penh to Neak Loueng on National Road No.1 was conducted by the Government of Japan.

Source: Prepared by JICA Study Team

The criteria adopted in the previous projects are not the same even under the same geographic features. The ADB section between Neak Loeung and Viet Nam border (hereinafter called "ADB Section") adopts AASHTO as its design standard for designing the horizontal and vertical alignment. The National Road No.1 (NR-1) section between Phnom Penh and Neak Loeung, which is being improved by JICA (hereinafter called "JICA Section"), adopts Asian Highway Standard and Road Design Standard in Cambodia (hereinafter called Cambodian Standard)[1] for designing the grade and AASHTO and Japanese Standard for other design criteria.

Major design elements adopted to various projects in Cambodia and typical cross-sections of embankment, which are relevant to the project road for reference, are demonstrated in Appendix 5.1.

5.1.2 Design Standard for the Project Road

The following factors determine the design criteria for the project road.

1) The project road forms partly the Asian Highway Route AH-1 and the 2nd East-West Economic Corridor, connecting Thailand – Phnom Penh – Ho Chi Minh.

2) The project road is located between ADB Section and JICA Section[2].

[1] The Road Design Standard in Cambodia was established in 1999
[2] JICA Section covers between Phnom Penh and Neak Loeung.

3) A sufficient level of service needs to be developed and maintained with full understanding of local characteristics in Cambodia.

Accordingly, the overall design criteria and standard for the project road are developed based on AASHTO. Detailed regulations and parameters like a design vehicle, coefficient of the friction between tires and pavement, driver's eye height are examined referring to the Japanese Standard and Cambodian Standard to reflect local characteristics.

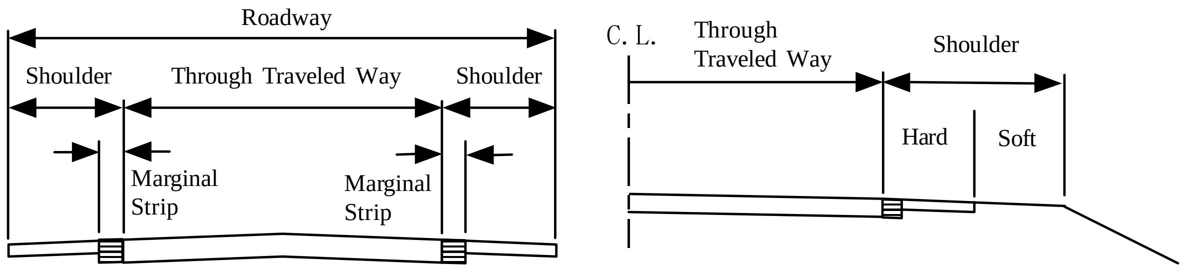
Some basic technical terms are defined and commonly used as follows (refer to Figure 5.1.1):

Roadway : the portion of the highway, composed of the traveled way and the shoulders

Traveled Way : the portion of the roadway for vehicular movements excluding shoulder.

Shoulder : the portion of the roadway for accommodation of stopped vehicles, for emergency use and for lateral support of sub-base, base and surface courses. A shoulder is classified by the hard shoulder (paved or surface treated) and the soft shoulder (covered by sub-base material).

Marginal Strip: the portion of the shoulder extended with the same pavement structure of the traveled way (usually 0.25 m – 0.5 m). This space is also used for road marking along both edges of the traveled way.



Source: Prepared by JICA Study Team

Figure 5.1.1 Configuration of Road Structure

5.1.3 Design Criteria for Geometric Design

(1) Basic Factor

1) Functional Classification

The following factors are considered to determinate functional classification of the project road.

- The project road forms the levee, which develops a flood-free area in the east bank, and it passes through some scattered residential area. A flood-free area is expected to develop as the Neak Loeung Regional Center.
- The project road eventually provides the bypass service for congested Neak Loeung town and ferry transport.
- The project road accommodates international transport, as it forms part of Asian Highway Route AH-1, the 2nd East-West Economic Corridor and National Road No.1.

The recommended functional classification is the "Rural Arterial Road" with the primary road function of high mobility, and given the priority to motorized vehicles (refer to Appendix 5.1 where major design elements by donors are exhibited).

2) Design Vehicle

Vehicles identified in the project area are classified into three categories: Passenger Car, Truck and Semi-trailer. Passenger Car includes sedan, wagon van and pick-up, while Truck includes bus and single-unit truck. Semi-trailer represents truck tractor-semi-trailer combination with 42.5ft container.

In terms of the design vehicle, Cambodian Standard adopts AASHTO and classifies it by passenger car (P), single unit truck (SU) and truck combination (WB-15). Japanese Standard adopts the smaller design vehicle by reference to AASHTO as shown in Table 5.1.2.

Taking into account of size and composition of vehicles in Cambodia, the recommended design vehicles to the project road are developed based on both AASHTO and Japanese standard as shown in Figure 5.1.2.

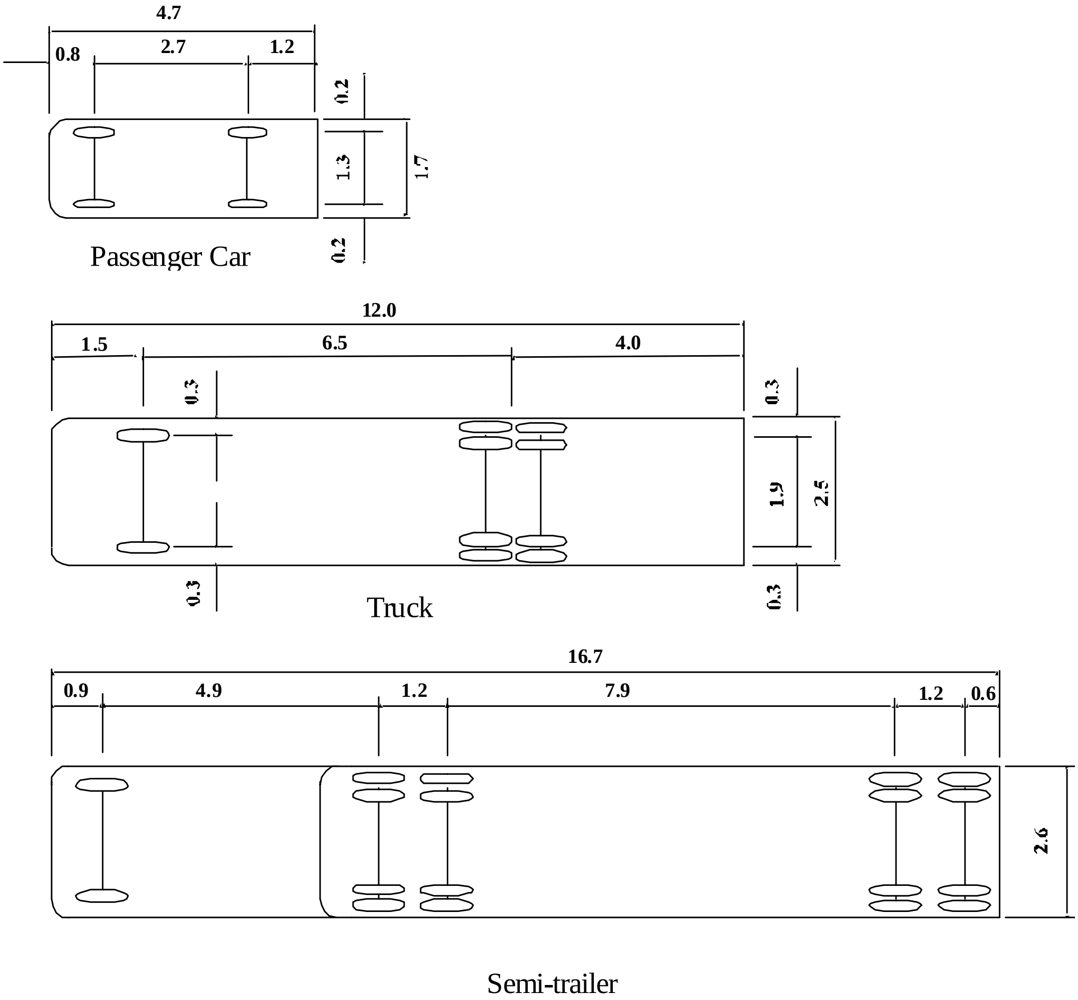
The design vehicle becomes the determinant of the road design: Semi-trailer for "Traveled Way", the Truck for "Major At-grade Intersection", and the Passenger Car for "Minor At-grade Intersection".

Table 5.1.2 Comparison of Design Vehicle Dimensions

Unit: meter

Standard		AASHTO			Japanese Standard		
Type of Vehicle		Passenger Car	Single Unit Truck	Truck Combination	Passenger Car	Truck	Semi-trailer
Symbol		P	SU	WB-15	-	-	-
Wheel Base		3.4	6.1	6.1/ 9.1	2.7	6.5	4.0/ 9.0
Overhang	Front	0.9	1.2	0.9	0.8	1.5	1.3
	Rear	1.5	1.8	0.6	1.2	4.0	2.2
Overall Length		5.8	9.1	16.7	4.7	12.0	16.5
Overall Width		2.1	2.6	2.6	1.7	2.5	2.5
Height		1.3	4.1	4.1	2.0	3.8	3.8
Turning Radius		7.3	12.8	13.7	6.0	12.0	12.0

Source: Prepared by JICA Study Team



Note: All Unit in Meter
Source: Prepared by JICA Study Team

Figure 5.1.2 Design Vehicles

3) Design Speed

Design speed is the maximum safe speed and is determined considering such factors as:

- Type or classification of the road
- Type of terrain
- Roadside land use and degree of access control
- Design speed of adjacent section(s)

The design speed determines some geometric elements, i.e. horizontal and vertical alignments, sight distances, provision of super-elevation. The design speed also determines other features such as traveled way width and roadside clearance to a lesser degree.

Design speed adopted in the ADB Section is 100 km/h, while JICA Section is 80 km/h. The recommended design speed to the project road is 80 km/h for the following reasons.

- The road is expected to accommodate a high mobility for international transport use.
- The road is located in the rural area and bypasses the urbanized area.

- Less speed maintains a stable traffic flow on the 2-lane road with non-access control.
- Construction costs and negative social impacts will be reduced when the design speed is reduced.
- The difference in design speeds of the adjoining sections can be adjusted by gradual changes of geometric design standards.

4) Horizontal and Vertical Clearances

a. Horizontal Clearance
Figure 5.1.3 illustrates horizontal clearance limit, which indicates the outer edge of the shoulder.

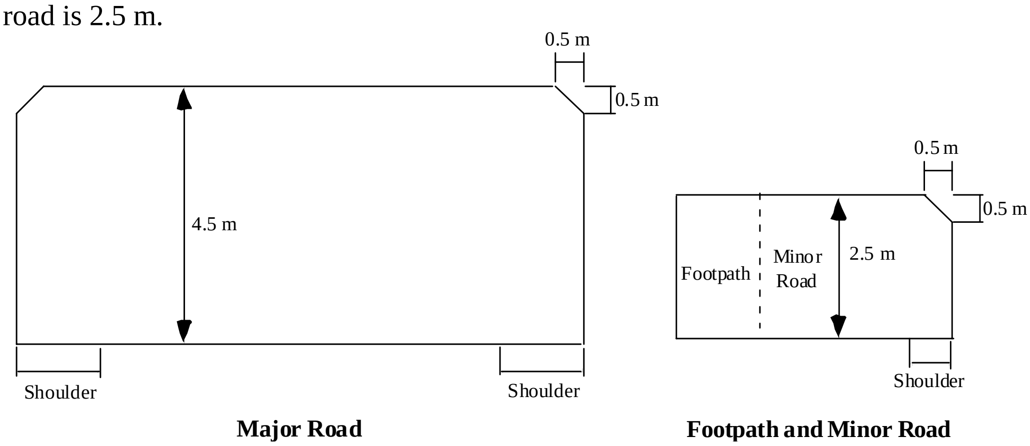
b. Vertical Clearance for Major Road
Table 5.1.3 compares vertical clearance by different design standards, i.e. AASHTO, Japanese Standard and Cambodian Standard. The recommended vertical clearance is 4.5 m, which accommodates the allowance of the headroom and overlaid thickness.

Table 5.1.3 Vertical Clearance for Major Road

Standard	AASHTO	Japanese Standard	Cambodian Standard
Vertical Clearance	4.3 m	4.5 m	(4.1m)

Note: Parentheses shows height of design vehicle.
Source: Prepared by JICA Study Team

c. Vertical Clearance for Minor Road and Pedestrian
The recommended vertical clearance for the minor road and pedestrians to the project road is 2.5 m.



Source: JICA Study Team

Figure 5.1.3 Horizontal and Vertical Clearance

5) Type of Pavement

The pavement structure should be durable for all-weather use. The pavement needs to be designed to fulfill such functions as:

- A sufficient thickness and satisfactory internal strength to allow intended traffic loads.
- An adequate compaction to avoid the penetration or internal accumulation of moisture.

- A smooth and skid resistant surface to avoid wearing, distortion and deterioration by weather.

There are two types of flexible pavement, i.e. asphalt concrete (AC) and bituminous surface treatment (BST). They have similar characteristics theoretically since they use the bitumen material. The recommended type to the project road is AC pavement from its economical feasibility and durability.

- AC pavement requires a larger initial cost but a less maintenance cost. BST pavement needs a less initial cost but an excessive maintenance cost to maintain the same serviceability as AC pavement generates.
- BST pavement requires additional costs for the frequent rehabilitation works unless proper and timely repair works are undertaken.
- Although AC pavement needs the asphalt mixture and the pavement equipment, a secure and high quality of pavement is required. Meanwhile, BST pavement requires skilled workers for quality pavement but in reality, the pavement is not always persistent perpendicularly and laterally. Especially, a corrugating edge of the pavement hampers a driver to properly visualize the road alignment and aggravates easier penetration of storm water into the pavement structure.
- BDT is not suitable under rainy environment compared with AC generally

(2) Number of Lanes

The current daily traffic volume, loaded by the ferry, is 2,995 vehicles (2,376 PCU) according to the traffic survey in May 2004. Table 5.1.4 shows future traffic demand in the study section and neighboring sections.

Table 5.1.4 Traffic Demand Forecast by Sections

Section		JICA Section (54km+500)	The Study Section	ADB Section (Link No. C062)
Traffic Survey Year		2004	2004	1997
Target Year of Forecast		2016	2020	2010
Traffic Volume (PCU/day)	Motorbike	2,179	1,202	3,938
	Light Vehicle	4,806	6,234	4,514
	Heavy Vehicle	966	1,721	2,171
	Total	7,951	9,157	10,622

Note: Traffic volume of JICA Section is shown in 12 hours.
Conversion rates of 1.165, 2.241 and 0.254 are applied to light vehicles, heavy vehicles, and moterbikes, respectively.
A Large Vehicle ratio of the ADB Section is assumed at 20% of 4-wheel vehicles (vehicle/day).
Source: Prepared by JICA Study Team

The recommended number of lanes to the project road is 2-lanes, which is affordable for the future traffic demand. The number of lanes for the adjoining JICA Section (western side of the river) and ADB Section (eastern side of the river) are also designed by 2-lanes.

(3) Cross Section Elements

1) Lane Width

Table 5.1.5 shows the lane width of the rural arterial roads in different countries. AASHTO (U.S.A.) adopts the widest lane width of 12 feet (3.60 m), while other countries adopt 3.50

m, for instance, for Rural Arterial Road as well as Class II of Aisin Highway. Eventually, the recommended lane width to the project road is 3.50 m.

Table 5.1.5 Lane Width By Countries

Countries	U.S.A.	Sweden	France	Japanese	Cambodia	Asian Highway
Classification	-	-	-	Category 3, Class 1	R5	Class II
Lane Width	3.60 m (12 ft)	3.50 m	3.50 m	3.50 m	3.50 m	3.50 m

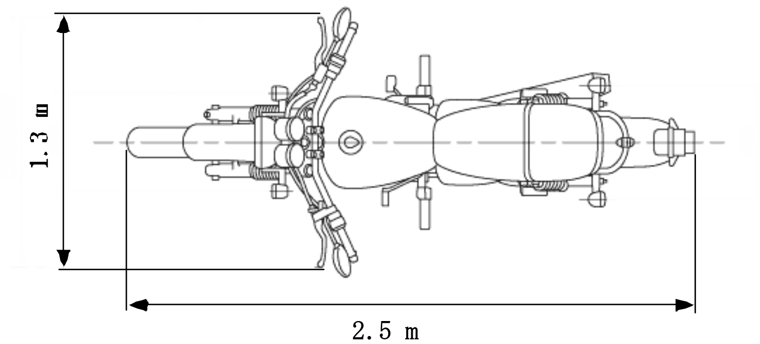
Source: Prepared by JICA Study Team

It should be noted that JICA Section as well as the Study adopts 3.5 m lane width, while ADB Section adopts 3.75 m lane width. The gap of 0.25 m between the two sections is adjusted at a taper section of the intersection.

2) Motorbike Lane Width

The project road accommodates a motorbike lane. One of the salient features of the traffic characteristics in the study area is a large number of slow-moving vehicles such as bicycles, motorbikes, tractor and animal carts. Among them, motorbikes account for the majority. A mixture of motorbikes and ordinary 4-wheeled vehicles may reduce the traffic capacity as well as traffic safety. Therefore, the Study recommends to separate them by the provision of the motorbike lane.

Figure 5.1.4 illustrates dimensions of motorbike stipulated in “Japanese Regulation of Road Transportation Vehicle”, which is 1.3 m wide and 2.5 m long. Although a typical motorbike in Cambodia is relatively smaller than the design vehicle in Japan, 1.3 m-width is assumed acceptable for the motorbike lane in due consideration of a motorbike trailer observed frequently in the project area.



Source: Prepared by JICA Study Team

Figure 5.1.4 Dimension of Motorbike

The motorbike lane should be reserved for a stuck or out-of-order motorbike and the space for inspection. The recommended width on the project bridge is 1.5 m for the following reasons:

- Although JICA Section accommodates 2.5 m motorbike lane, that on the project bridge can be reduced to 1.5 m like Kizuna Bridge on NR-7 from an economical viewpoint.
- A typical cross section of the ADB Section does not accommodate the motorbike lane, instead ADB Section accommodates a hard shoulder of 1.5 m wide and which functions as a motorbike lane.

- Table 5.1.6 shows relationship between motorbike width and traffic volume on major bridges. The motorbike lane width of 1.5 m is considered capable of accommodating the 2020 future traffic demand of the project bridge, which is estimated to grow at 7% per annum.
- Headway between motorbikes on each bridge is calculated and compared as shown in Table 5.1.7. From the result of calculation, the average headway for the project bridge is estimated as 11.3 sec and it is the longest among the bridges. (refer to Appendix 5.1)

Table 5.1.6 Comparison of Traffic Volume and Motorbike Lane Width by Bridges

Bridge Name		Monivong Bridge	Chruoy Changvar Bridge	The Study Bridge	Kizuna Bridge
Traffic Survey Year		2004	2000	2004	1995
Target Year of Forecast		-	-	2020	2021
Traffic Volume (PCU/day)	Motorbike	22,752*	9,250*	1,202*	1,971*
	Light Vehicle	12,880*	704*	6,234*	4,354
	Heavy Vehicle	1,277*	8,559*	1,721*	1,866
	Total	36,909	18,513	9,157	8,191
Motorbike Lane Width		1.9 m	1.9 m	1.5 m	1.5 m

Note: As for the numerical value with the asterisk, the conversion rates of 1.165, 2.241 and 0.254 are applied to light vehicles, heavy vehicles, and motorbikes respectively.
A heavy vehicle ratio of Kizuna Bridge is assumed at 30% of the total 4-wheel vehicles (PCU/day)
Traffic volume of Monivong Bridge and Chruoy Changvar Bridge were surveyed during 12 hours in daytime.
Source: Prepared by JICA Study Team

Table 5.1.7 Comparison of Motorbike Headways by Bridges

Br. Name	Items	Unit	Calculations	Remarks
The Study Bridge (Year 2020)	Motorbike Daily Traffic Volume	Veh/day	4,732	
	Hourly Traffic Volume	Veh/hour	563	Peak Hour Ratio (%): 11.9
	Hourly Traffic Volume per Direction	Veh/hour/direction	318	Heavy Direction Ratio (%): 56.5
	Headway by Time	Sec.	11.3	
	Headway by Length	m	94.3	Assumed Speed (km/h): 30
Kizuna Bridge (Year 2021)	Motorbike Daily Traffic Volume	Veh/day	7,760	
	Hourly Traffic Volume	Veh/hour	931	Peak Hour Ratio (%): 12.0
	Hourly Traffic Volume per Direction	Veh/hour/direction	512	Heavy Direction Ratio (%): 55.0
	Headway by Time	Sec.	7.0	
	Headway by Length	m	58.6	Assumed Speed (km/h): 30
Monivong Bridge (Year 2004)	Motorbike Traffic Volume in 12 hr.	Veh/12hr.	90,827	
	Daily Traffic Volume	Veh/day	118,075	Daytime Ratio (%): 1.3
	Hourly Traffic Volume	Veh/hour	9,446	Peak Hour Ratio (%): 8.0
	Hourly Traffic Volume per Direction	Veh/hour/direction	5,195	Heavy Direction Ratio (%): 55.0
	Headway by Time	Sec.	0.7	
	Headway by Length	m	5.8	Assumed Speed (km/h): 30
Chruoy Changvar Bridge (Year 2000)	Motorbike Traffic Volume in 12 hr.	Veh/12hr.	36,418	
	Daily Traffic Volume	Veh/day	47,343	Daytime Ratio (%): 1.3
	Hourly Traffic Volume	Veh/hour	3,787	Peak Hour Ratio (%): 8.0
	Hourly Traffic Volume per Direction	Veh/hour/direction	2,083	Heavy Direction Ratio (%): 55.0
	Headway by Time	Sec.	1.7	
	Headway by Length	m	14.4	Assumed Speed (km/h): 30

Source: JICA Study Team

Generally, speed friction is caused between a motorbike and a car, because the driving speed of the motorbike is slower compared to that of the car. In Cambodia, motorbikes are often observed to overflow into the car lane for overtaking slow motorbikes. Such behavior of motorbikes brings about not only decreasing traffic capacity, but also endangering road safety as experienced at the Monivong Bridge.

Although a motorbike lane width of 1.5 m is enough to accommodate the traffic demand of the project bridge, countermeasures against the traffic accident to suit the motorbike dimension should be examined in consideration of traffic characteristics in Cambodia.

It is effective to separate cars and the motorbikes completely by physical traffic barriers such as the guardrail to avoid mixed traffic. It is, however, necessary to provide an additional space to install the facility. Taking an example of Chruoy Changvar Bridge, there is a 6 cm difference in level between the motorbike lane and the ordinary vehicle lane. Such a difference in level separates the mixed traffic and keeps the traffic effectively in the respective lane.

Therefore, it is recommended that a large-scale physical barrier should not be installed, but facilities such as thick road marking and a traffic safety device like a delineator should be considered as incidental to traffic management.

3) Shoulder Width

Shoulder widths of 0.5-3.6 m are generally adopted in the highway. The recommended shoulder width for the project is 1.0 m, considering an economic constraint, land acquisition condition and service level.

The shoulder width of 3.0 m is stipulated for the Rural Highway (R5) in Cambodian Standard. This requirement meets when the motorbike lane is considered as part of shoulder, so that the total shoulder width on the embankment section will actually become more than 3.0 m.

4) Marginal Strip Width

The marginal strip has functions such as:

- Space for marking to induce the driver's glance
- Securing part of width of side clearance
- Improvement of road safety to the vehicle that deviates from the lane

The recommended marginal strip width is 0.25 m, which is the outer edge of the 4-wheel vehicle lane and that of the motorbike lane in a whole stretch excluding the bridge section.

In Cambodia, the marginal strip along the outer edge of the bike lane is generally omitted in the bridge section from the economical viewpoint. However, a lot of traffic accidents of the motorbike are observed on the bridge; especially some motorbikes have collided with the lighting pole on Chruoy Changvar Bridge.

The traffic on the project bridge is characterized as follows:

- High large vehicle ratio.
- Long slope length with a steep gradient.
- High design speed as the international trunk road.

Considering these characteristics, the marginal strip is considered necessary in a minimum width of 0.25 m along the outer edge of the motorbike lane on the bridge section.

5) Space for Installation of Utilities and Inspection

Following the design standard and road improvement practices in Cambodia, a width for utilities is recommended at 0.5 m on the embankment section. This space accommodates road signs, guard posts, road lighting, electric wire poles and telegraph poles.

In the bridge section, the recommended width is 0.75 m. This space is utilized not only for installation of public utilities but also for inspection and maintenance works, evacuation route and side clearance.

It is assumed that the sidewalk on the project bridge is not necessary from consideration that there will be few pedestrians to pass through the bridge, because the bridge length exceeds 2 km, and the total length is more than 5 km, including the approach roads on the east and west banks.

6) Crossfall of Traveled Way and Shoulder

It is for DBST that a crossfall of 2.5% to 3.0% on bituminous surface is stipulated in Cambodian Standard, and that of 2.0% is enough for the asphalt concrete, considering the advantage of the rapid drain on the pavement and also the comfort of drivers. Since the crossfall of 2.0% is adopted for the asphalt concrete surface of the approach road of Kizuna Bridge, the same crossfall is applied to the project road.

Discussions on detailed elements of the highway standard are described in Appendix 5.1, which covers those mentioned below:

- Sight distance
- Horizontal alignment (Maximum super elevation, Minimum radius, Sharpest curve without super elevation, Value of super elevation on curvature (i), Minimum transition curve length, Minimum horizontal curve length, Minimum radius of curve and Superelevation runoff)
- Vertical alignment (Maximum grade and Minimum vertical curve length and radius)

5.1.4 Summary Recommendations of Geometric Design Criteria and Standard

Table 5.1.8 summarizes the geometric design criteria, and Figure 5.1.5 illustrates the typical cross section of the Project. In the course of analysis discussed above, the typical cross sections for this study adopt the same design criteria as applied to the embankment section of JICA Section and the bridge section of Kizuna Bridge.

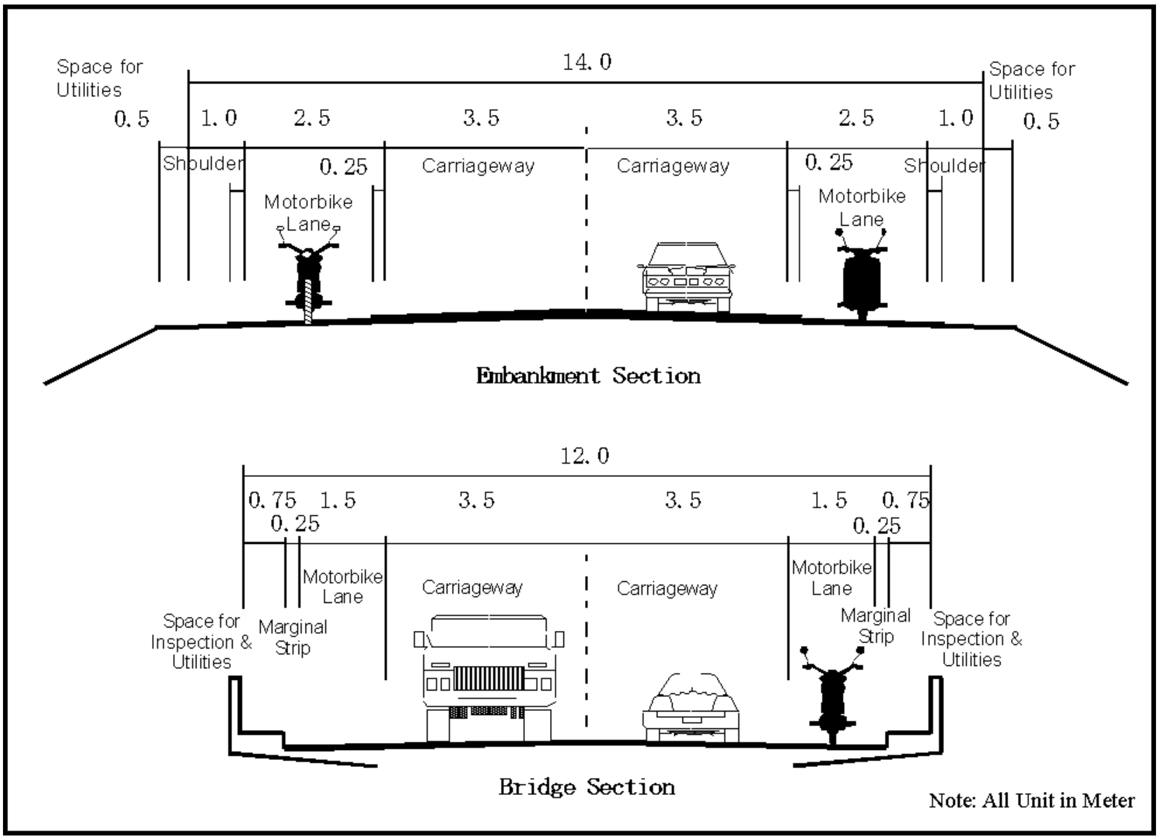
Table AP.5.1.19 compares the geometric design criteria by different projects for reference. Figure AP.5.1.3 illustrates the comparison among the bridge cross sections over the Mekong River in different countries.

Table 5.1.8 Summary of Geometric Design Criteria for the Project

Items	Unit	Design Criteria
0. Terrain	-	Flat
1. Road Classification	-	Rural Arterial
2. Design Speed	Km/h	80
3. Vehicle Lane Width	m	3.50
4. Motorbike Lane Width	m	2.50 (1.50)
5. Shoulder Width	m	1.00 (N.A.)
6. Marginal Strip Width	m	0.25 (0.25)
7. Space for Inspection and Utilities	m	0.50 (0.75)
8. Crossfall of Pavement	%	2.0
9. Crossfall of Earth	%	4.0 (N.A.)
10. Stopping Sight Distance	m	110
11. Maximum Superelevation	%	6.0
12. Minimum Horizontal Curve Radius	m	280

Items		Unit	Design Criteria
13.	Minimum Horizontal Curve Length	m	140* or 1,000/θ
14.	Minimum Transition Curve Length	m	70
15.	Sharpest Curve Radius without Transition Curve	m	1,000
16.	Sharpest Curve Radius without Superelevation	m	3,500
17.	Max. Relative Slope for Superelevation Runoff	-	1:150
18.	Maximum Grade	%	4.0
19.	Minimum Vertical Curve Length	m	70
20.	Minimum Vertical Curve Radius on Crest	m	2,850
21.	Minimum Vertical Curve Radius on Sag	m	2,300
22.	Type of Pavement	-	Asphalt Concrete

Notes: 1. θ shows intersection angle in degree for horizontal curve (min. 2 degrees).
2. The figure with asterisk shows absolute value in case that θ is more than 7 degrees.
3. The figure in parenthesis shows value for bridge.
Source: JICA Study Team



Source: JICA Study Team

Figure 5.1.5 Typical Cross Section of Project Road

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

5.2.1 Background

The 1st Phase Study on the Construction of the 2nd Mekong Bridge concludes that "Route A" is the most appropriate route among the alternatives using the Analytic Hierarchy Process (AHP) method in Chapter 4. The Study appreciated that Route A will stimulate Neak Loeung Town to grow as a regional center and help to minimize such economic and social impacts as losses in ferry related businesses, traffic congestion at the Neak Loeung built-up area and a bottleneck of traffic flow at the ferry on National Road No. 1.

The location of the Project is planned not to be on the existing Neak Loeung Ferry but to be 1.6 km north of the existing ferry terminal of the Neak Loeung side. The approach road of the Project starts at Ampil Tuek Village 3 km north of the existing ferry terminal of Phnom Penh side along NR-1 and it ends at Phum 1 Village 1.2 km east of the existing ferry terminal of Neak Loeung side along NR-1, with total 5.4 km route length.

5.2.2 Scrutiny of the Selected Route

(1) Points to be considered in the Scrutiny of the Selected Route

The selected route is scrutinized to decide a detailed alignment of the project for the preliminary design, taking into consideration the designated roles and functions of the project road.

The scrutiny of the selected route is carried out from the following aspects:

- Design Controls
- Physical Constrains
- Toll Levy System
- Road Network in the Project Area (including new service roads)

Site investigations, which consist of topographic survey, environmental impact survey, geological survey, hydrological survey, land use survey, traffic survey as well as data collection such as satellite photos, are carried out to reveal natural, physical and social conditions of the project area. A sample result of the site investigation along the relevant part of NR-11 is presented in Appendix 5.2, comparing topographic maps in 2003 and 2005.

These basic data are referred to for setting a detailed alignment of the selected Route A.

(2) Design Controls

To realize roles and functions of the project road as an international trunk route, it is necessary to determine major design controls which elements have close relation horizontally and longitudinally to determine the alignment. Although design controls such as design standard and design conditions are described in detail in Section 5.1, principal design controls are as follows:

- Road Classification: Rural Arterial Road
- Design Speed: 80 km/h
- Typical Cross Section: Undivided 2-lane with motorbike lane
- Minimum Horizontal Curve Radius: 280m
- Maximum Grade: 4.0%
- Navigation Clearance: W=180 m, H=37.5 m above HWL

Furthermore, the alignment in the bridge section is desirable to avoid a curve and to be right-angled in the direction of the current of the river.

(3) Physical Constrains

Especially in the urban area, there exist several land lots and properties that will be affected by road development. Some of those lots and properties are so important that a project road should be controlled to avoid and to avert adverse social impacts on them or to avoid considerable compensation costs. These objects are called "Primary Controlling Points".

Factories, public facilities such as an orphanage and a steel tower for telecommunication and cemetery are found along Route A, and they should be classified as primary controlling points.

"Secondary Controlling Points" are land lots or properties that are desirable to stay away from the project alignment, if possible. Residential area, stout buildings, graves and irrigation channels are regarded as secondary controlling points.

To clarify the land use and importance of public and private facilities along and around the selected Route A, the topographic map in the scale of 1:5,000 was examined and updated by the site reconnaissance.

(4) Toll Levy System

The Project can be operated as a toll bridge, and accordingly a toll will be levied on road users who will cross the Mekong River. A barrier-type toll plaza on the through way is the most suitable for the toll bridge due to efficiency of toll collection and convenience to users and management of the toll operator.

Location of the toll plaza is preferable at an embanked straight section avoiding sharp horizontal curve or steep gradient from road safety point of views. Further, it is required not construct a crossroad between the bridge and the toll plaza.

From these requirements, it is recommended to construct the toll plaza at the straight section on the east bank right after passing through the bridge from the west and turning to the south.

(5) Road Network

To maintain the roles and functions of the project road, it is necessary to formulate an appropriate road network in the study area. The approach road of the Project is planned to connect with several local roads which either exist already or planned in the study area to collect/distribute local traffic.

The existing and future traffic demands are characterized mainly as follows:

- Traffic on NR-1 over the project bridge is the main flow of the area traffic.
- Traffic that passes over the project bridge to/fromNR-11 will be developed.
- Through traffic is observed in Neak Loeung which travel between NR-11 and NR-1 section of Neak Loeung~Viet Nam border.
- Local traffic between the existing roads and the approach road will be generated.
- It is necessary to take the following measures to meet and accommodate these traffic demands.
- Horizontal curves should be incorporated into designing intersections where both ends of the project road and NR-1 meet. Therefore, it is required to keep the consistency of the geometric design between the project road and NR-1.
- The eastern approach road will function not only as the levee but also as the bypass to accommodate the Neak Loeung through traffic, and as the consequence form the flood-free area together with the existing NR-1 and NR-11.

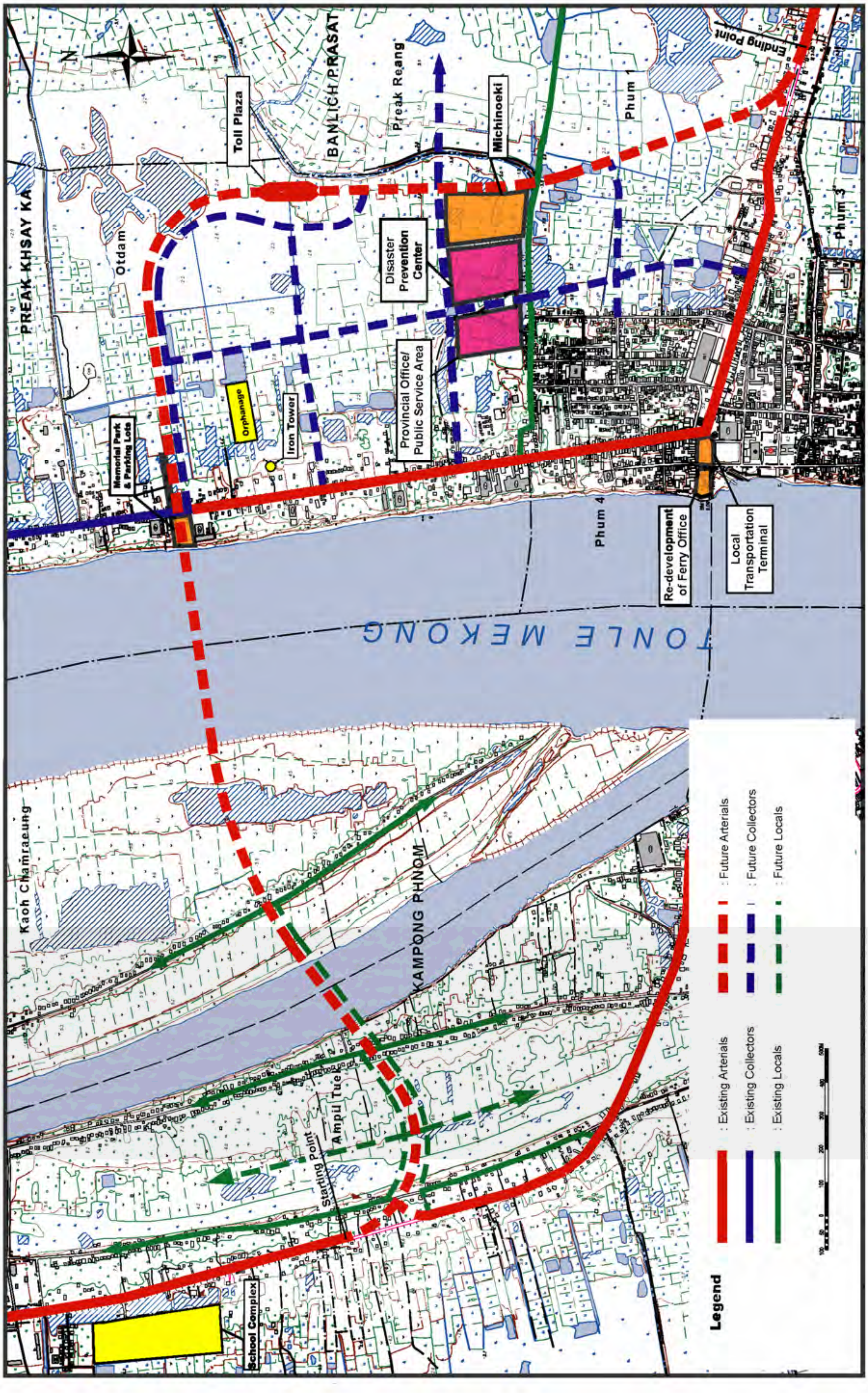
- Service roads should be arranged appropriately to assure necessary access function of roads, considering the local traffic situation and roadside conditions.

Furthermore, to formulate the road network, it should be considered that roads classified by the hierarchy are arranged in a suitable interval and be reflected in the land use plan for the regional development.

5.2.3 Description of the Route Alignment

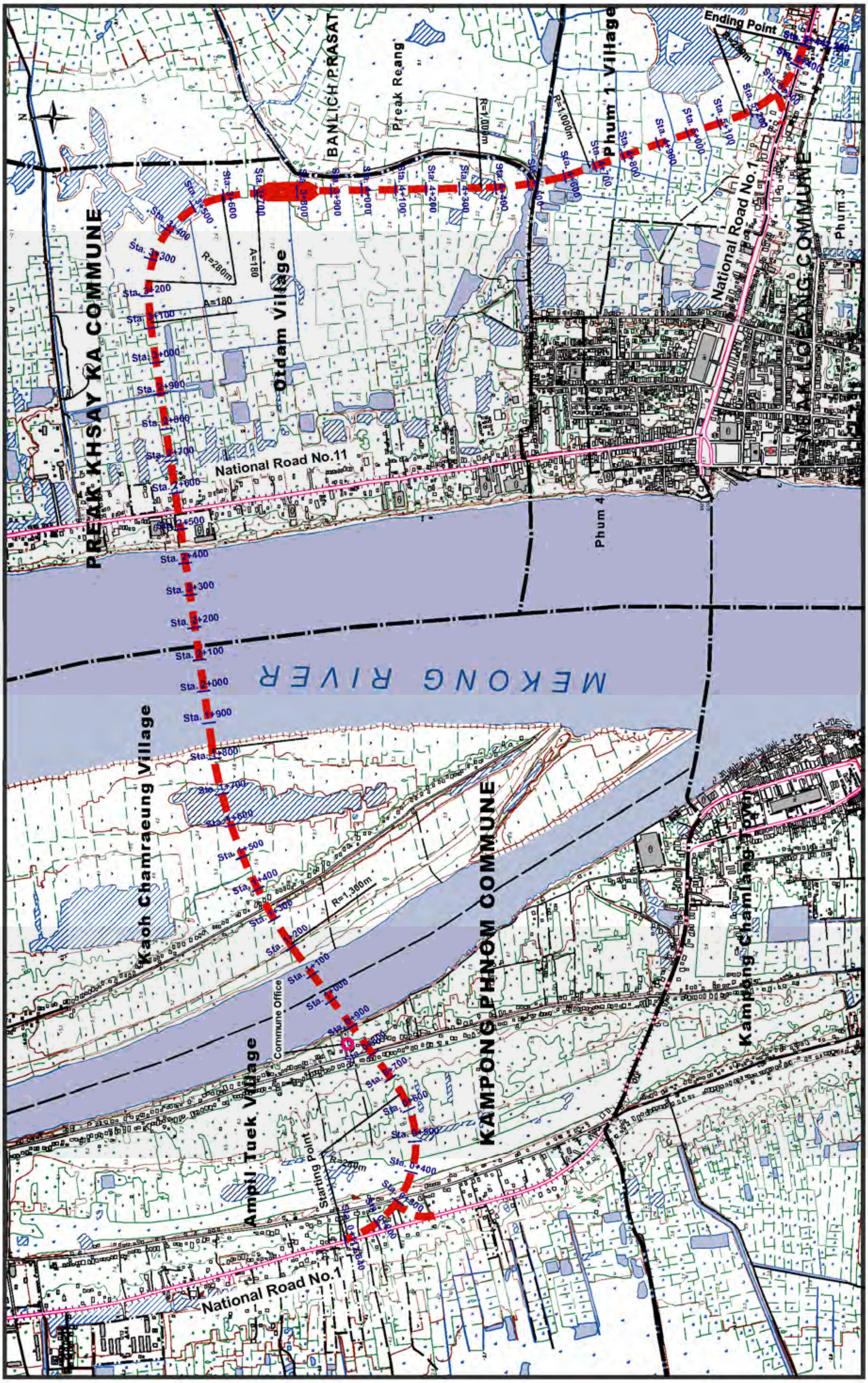
Based on the required conditions discussed in Section 5.2.2, the future road network is planned as shown in Figure 5.2.1, and the alignment of the project road is proposed as shown in Figure 5.2.2.

Detailed description of the fixed route alignment is presented as follows:



Source: JICA Study Team

Figure 5.2.1 Future Road Network of the Study Area



Source: JICA Study Team

Figure 5.2.2 Proposed Alignment of the Project

The river crossing point is located 1.6 km north from Neak Loeung Ferry Terminal on the east bank, and the total length of the route is 5.330 km.

The starting point is located at Sta. 0+112.640 that corresponds to Sta. 53+015.946 on the alignment of the basic design conducted by JICA in 2004 for the Phnom Penh - Neak Loeung section of NR-1, and which basically follows the existing centerline of NR-1, but proposes the elevation of approximately 70 cm higher than the exiting level in the basic design.

Some houses are found around the starting point area along NR-1. Further, there is a residential area, called Ampil Tuek Village and located between NR-1 and a 3 m-width local road. These two roads lie in parallel at an interval approximately 70 m apart. The right-of-way of NR-1 is secured 25 m in width on east side from the existing centerline of NR-1, according to the basic design.

The route diverts from NR-1 to turn eastward along the curve in a radius of 280 m; passes aiming at open space to minimize the adverse social impact; and crosses the 3 m-width local road at Sta. 0+333.641.

The route keeps turning eastward and passes an old river channel where the truck farm extends now. Graves are scattered in the truck farm, and it is not avoidable for the project alignment to cross some graves. The route passes another 5 m-width local road at Sta. 0+806.897 that is located on the natural levee of 7 to 8 m in height. Neatly maintained residential area extends along the local road, and the housing density in this area is lower than the northern area. The route manages to avert the commune office of Kampong Phnom and passes by the south of the office, although several houses will be affected in this local road area.

The route at Sta. 0+900 faces the branch stream of the Mekong River, which has a width of 440 m in lateral and an altitude of 1.4 m in the riverbed. A steep river terrace is formed by the erosion of the Mekong River at a different height of approximately 7 m.

The Bridge section will start from the top of the river terrace, and pass over the 480 m-width river island by a grade separation structure in Kaoh Chamraeung Village, and incorporate a gradual curve of 1,300 m in radius in the river island section. This is because the approach bridge of the Project is planned to become the elevated viaduct so as to secure the navigation clearance of the Mekong River of 180 m in width and 37.5 m in height at Sta. 2+135.

After the river island, the route leads to the main stream of the Mekong River, which has a width of 600 m in lateral and an altitude of minus 20 m in the riverbed. The route runs to cross the Mekong River, keeping a right angle against the river flow.

After crossing the Mekong River, the route reaches an open space between a rice mill factory and a distillery (under shutdown) on the east bank. Then, the route will fly over NR-11 at Sta. 2+533.027 in a way similar to the river island.

The route will face the cluster of houses in the east of NR-11 to some extent. However, the route again passes through open spaces and the soft ground from Sta. 2+660 to Sta. 4+460 such as agricultural lands, marshy areas, ponds and forest areas in Otdam Village. In this section, the route changes the alignment around the end of the bridge into the south while brushing against the fringe of the pond, and the curve will be installed in a radius of 280 m. And, the route is planned to extend southward to connect with the existing local road at Sta.4+521.873 after crossing a canal of 30 m in width which used to be an old river channel. The embankment of the approach road will close the canal and develop the flood-free area.

The route runs to the south-southeast by a gentle curve of 1,000 m in radius, and passes through open space such as the agricultural land and borrow pit site from Sta. 4+530 to Sta. 5+300. Finally, the route reaches NR-1 at Sta. 5+442.260 which was improved by ADB funds in 2003.

The ending point is located 1.2 km far from the ferry terminal at Neak Loeung side in Phum 1 Village, and it matches with the existing centerline. The route will come across several houses that stand along the northern row of NR-1.

5.3 Highway Engineering Design

5.3.1 Design Concept

The highway design of the project road basically considers the following factors:

- The project road forms a part of the Asian Highway Route AH-1 and the 2nd East-West Economic Corridor, connecting Thailand – Phnom Penh – Ho Chi Minh.
- The project road is located between the ADB section, which was improved from Neak Loeung to Viet Nam border in 2003, and JICA section, of which basic design was conducted between Phnom Penh and Neak Loeung in 2004. It is necessary for the project road design to cooperate and harmonize with these adjacent sections.
- The project road will be affected by flooding of the Mekong River. As an international road, the project road requires traffic safety even during the flood season of the Mekong River.
- It should be considered that the project road minimizes negative social impacts such as relocation and regional split into parts. Moreover, it is necessary to preserve the existing environment to the maximum extent.
- In view of intermediate and long-term perspectives of the future regional development, the flood-free area that is created by the project road should be fully utilized to encourage the development of the Neak Loeung Area as a multi-purpose regional center. Additionally, it is expected that the regional development help not only increase employment opportunities but also mitigate such negative social impacts as involuntary resettlements and impacts on businesses around the ferry terminal.
- The project road must satisfy the established design criteria discussed in the previous section 5.1. It is a primary concern to assure the traffic safety in designing the project road.

5.3.2 Design Section

A design section of the project road is defined to comprise a single section due to the following features of the project road:

- The terrain is flat throughout the stretch
- The land use along the route remains almost unchanged
- The traffic demand varies in a comparatively small range.

Therefore, the same design concept and design criteria will be applied to the whole stretch of the project road from the start to the end, excluding adjoining roads to connect with the project road.

5.3.3 Proposed Alignment

(1) Horizontal Alignment

As described in Section 5.2, the proposed horizontal alignment was scrutinized and revealed on the ground. The proposed horizontal alignment is justified and appraised appropriate in view of securing the design concept.

(2) Design High Water Level for Road Embankment

The design High Water Level (HWL) adopted for the project bridge design is 7.93 m, which corresponds to the 100-year return period. This return period is derived from the consideration of bridge life and reference to those applied to Kizuna Bridge in Cambodia and Can Tho Bridge in Viet Nam, which are located up and down stream of the Mekong River, respectively. Therefore, the 100-year return period is also applied to the HWL of the road embankment.

The flood water level in the eastern bank and the western bank including the Mekong River is different because of characteristics of the Mekong River Basin in the study area. The design HWL of the western bank as well as the project bridge is defined as 7.93 m but that of the eastern bank is defined higher than 7.93 m.

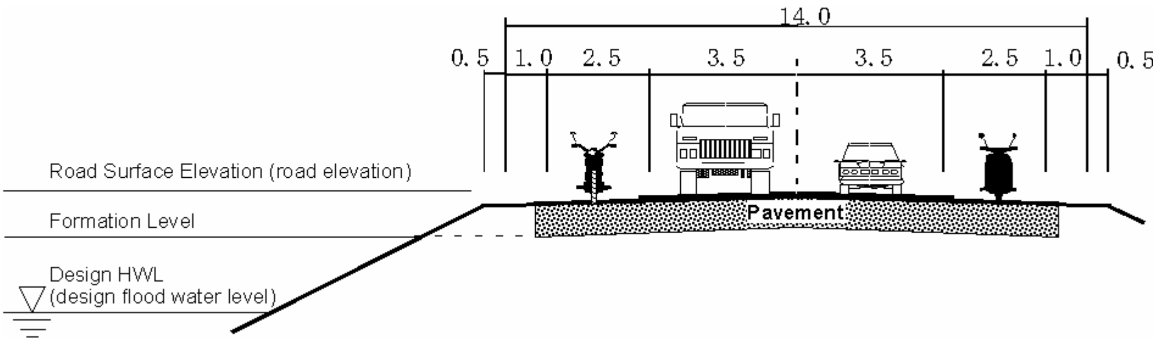
As discussed at Section 2.3.2, HWLs of the eastern bank and the western bank are analyzed to be 8.23 m and 7.80 m respectively after construction of the project bridge. The HWL simulation, however, is based on the discharge of the floodwater in 2000.

Compared with HWL of the Mekong River, the HWL of the western bank, i.e. 7.80 m, almost corresponds to that of the eastern bank for a 50-year return period. Therefore, a design HWL of the eastern bank, i.e. 8.35 m, is derived from the calculation result of 8.23 m plus 0.12 m, which is the difference in HWL between 50 and 100-year return periods.

(3) Minimum Elevation of Road Surface

1) General

A minimum elevation of the road surface, with regard to the flood water level, is one of the key issues in the highway design. It is widely accepted that the difference in height between road elevation and HWL is allowed to take 1m or higher. However, it is undesirable to define the minimum elevation of road surface to be excessively higher than HWL from the economic viewpoint. Especially, since the project road is located on the soft ground soil, it is required to keep the road elevation as low as possible from the geological viewpoint. Therefore, the relationship between each elevation is commonly used as shown in Figure 5.3.1.

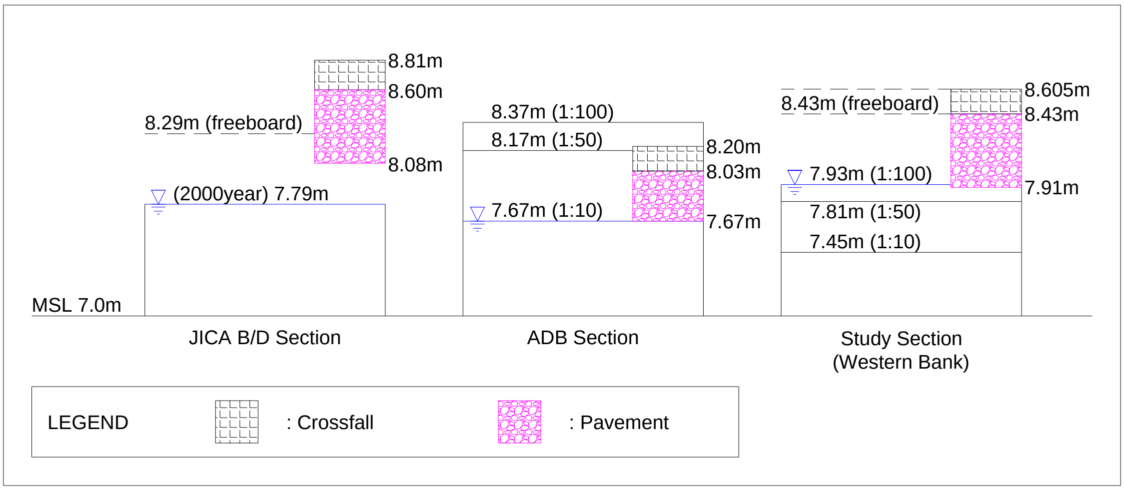


Source: JICA Study Team

Figure 5.3.1 Relationship among Different Elevations

The Study reviews the minimum elevation of the road surface adopted by the JICA Section and the ADB Section, of which results are described in Section 4.3.3, Progress Report (2) (September, 2005).

Figure 5.3.2 compares the relationship between pavement and design HWL among the relevant projects. As the result of the comparison between three projects, the proposed minimum elevation of road surface falls between other two projects. It is reasonable to allow that flood water soak to pavement layers once in 50 years. Therefore, the proposed minimum elevation of the road surface is justifiable, and as the consequence, 8.605 m is to be applied to the western bank and 9.025 m to the eastern bank for the Study, excluding the section connected with the ABD Section.



Note: Pavement thickness of the study section is assumed to be same as JICA Section.
Source: Prepared by JICA Study Team

Figure 5.3.2 Comparison among Relevant Projects Regarding Relationship between Road Elevation and Design HWL

(4) Vertical Alignment

The proposed vertical alignment will be gentle except for the bridge section, because the project road is located in the Mekong River Basin. The proposed vertical alignment is based on the following considerations.

- The established design criteria should be observed.
- The minimum elevation of the road surface is applied; 8.57 m to the western bank and 8.69 m to the eastern bank.
- The road elevation and gradient at starting and ending points of the project road should be used in coordination with the adjacent project sections.
- The navigation clearance must be assured.
- In the consideration of drainage for road surface, the minimum grade of 0.3% is recommended to apply.
- It should be avoided as much as possible to set a vertical curve to the section of toll plaza and at-grade intersection due to easing the road surface drainage.

(5) Results of Alignment Setting

Table 5.3.1 compares figures adopted for the project with those in the geometric design criteria for the project road proposed in Section 5.1. Consequently, the proposed alignment correctly satisfies the proposed design criteria.

Table 5.3.1 Summary of Geometric Criteria for the Project

	Items	Unit	Adopted Values	Design Criteria
1.	Maximum Superelevation	%	6.0	6.0
2.	Minimum Horizontal Curve Radius	m	280	280
3.	Minimum Horizontal Curve Length	m	263	140* or 1,000/θ
4.	Minimum Transition Curve Length	m	70	70
5.	Sharpest Curve Radius without Transition Curve	m	1,000	1,000
6.	Sharpest Curve Radius without Superelevation	m	-	3,500
7.	Max. Relative Slope for Superelevation Runoff	-	1:285	1:150
8.	Maximum Grade	%	4.0	4.0
9.	Minimum Vertical Curve Length	m	70	70
10.	Minimum Vertical Curve Radius on Crest	m	3,000	2,850
11.	Minimum Vertical Curve Radius on Sag	m	3,020	2,300

Notes: 1. θ shows intersection angle in degree for horizontal curve (min. 2 degrees).
2. The figure with asterisk shows absolute value in case that θ is more than 7 degrees.

Source: JICA Study Team

5.3.4 Service Road Plan

After construction of the project bridge, it is expected that the local traffic flow will change because of newly induced and generated traffic in the study area as described in Section 5.2.2. Based on the future road network and the classified intersections of the study area, the following service roads are considered necessary to treat local traffic from the viewpoint of road safety.

(1) Service Road at the West Bank

Houses and shops stand in a row along National Road No.1, and it is possible for them to access to NR-1 anywhere freely at present. Therefore, the mobility and the capacity of NR-1 will decrease and the problem of the road safety will become serious without any countermeasures. Considering the role and the function of the project road, it is preferable that the service roads are planned on both sides of the project road along its whole stretch, so that the project road will be fully access-controlled. However, the full access control plan for the whole length of the project road is not realistic from the viewpoint of the land acquisition and budget constraints.

There are two local roads in parallel with National Road No.1. The western local road is so close to the West Intersection that it is desirable to integrate this local road into the West Intersection. Another eastern local road is very close to the planned abutment of the project bridge. Since the vicinity of the project bridge should be fully access-controlled, it is proposed that the service road be set up on both sides of the section between the eastern local road and NR-1.

This service road is expected to contribute not only to strengthening the road safety, function and the role of the project road but also to the development of this area and preservation of the social environment.

Considering hierarchy of connecting roads, the service road is classified as “local”. Therefore, a design speed between 20 and 30 km/h is desirable, and gravel or earth surface is proposed as road surface.

(2) Bypass of National Road No.11

NR-11 Bypass is proposed to cope with the following objectives, as implied in Section 5.2.2:

- To meet and accommodate the through traffic in Neak Loeung which travel between NR-11 and NR-1 section of Neak Loeung~Viet Nam border and pass over the project bridge to/from NR-11.
- To enhance and secure the road safety in Neak Loeung
- To formulate the northern part of levee for the flood-free area
- To use as the construction road during construction period.

The horizontal alignment of NR-11 Bypass is planned in parallel with the approach bridge section and to connect with the approach road section to the south of the toll plaza away from a sufficient distance suitable to install the Toll Gate Intersection.

In order to preserve the safety of the project approach road, the approach section between the bridge abutment and the toll plaza should be access-controlled by installing a fence along there. In addition, this will ensure the security and control of toll gate management.

Considering the road hierarchy of connecting roads, NR-11 Bypass is classified as "collector". Therefore, the design speed between 40 and 60 km/h is desirable. At least, the design speed should be 40 km/h near the Toll Gate Intersection, otherwise the horizontal alignment of NR-11 Bypass will greatly apart from that of NR-1 of the study section. Road surface is recommended to be asphalt concrete pavement.

The proposed height of the NR-11 Bypass is designed as low as possible from the economical viewpoint when it connects with the embankment of NR-1 of study section. To set up the vertical alignment, the following points are considered:

- At least, a section of 50 m should be secured for an overlap with NR-1 of the study section from the point where NR-11 Bypass connects with the embankment of NR-1 of the study section.
- The proposed height of the section between toll plaza and Toll Gate Intersection should be adjusted to that of NR-1 of the study section, because toll management office is planned between NR-1 of the study section and NR-11 Bypass

5.3.5 Type and Location of Intersections

(1) Type of At-grade Intersection

The project road is planned to connect with local roads, which are the existing as well as planned in the study area to collect/distribute the traffic.

Based on the future road network, an appropriate intersection type is examined in consideration of the functional classification of the connected roads as shown in Table 5.3.2.

Table 5.3.2 Type of Intersection

Intersection Type	Classification of Intersecting Roads	
	Road Classification 1	Road Classification 2
Channelized Intersection	Arterial Roads	Arterial Roads
Intersection with Auxiliary Lane	Arterial Roads	Collector Roads
	Collector Roads	Collector Roads
Ordinary Intersection	Arterial Roads	Local Roads
	Collector Roads	Local Roads
	Local Roads	Local Roads

Source: JICA Study Team

(2) Location of At-grade Intersection

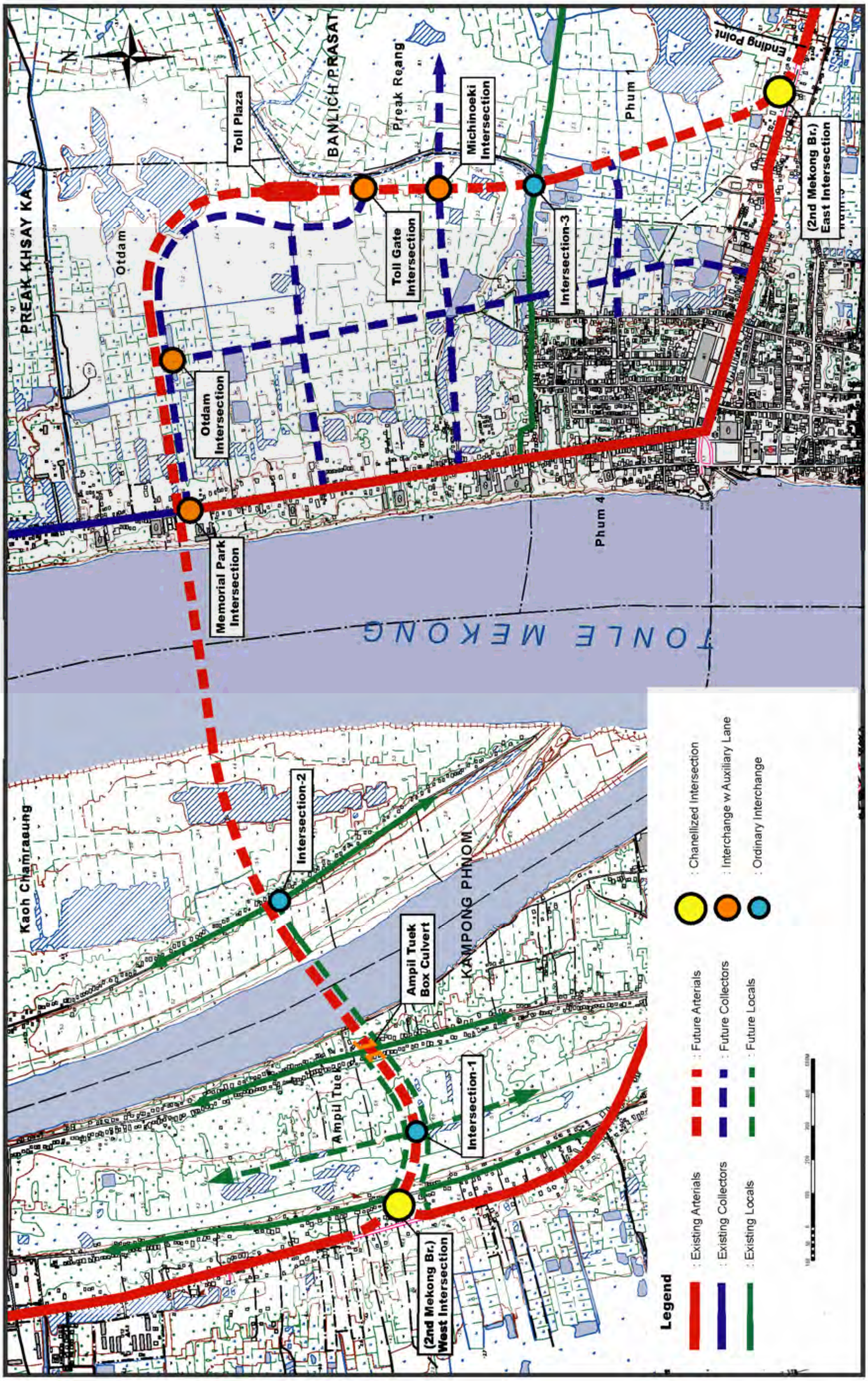
Following the type of intersection defined in Table 5.3.3, intersections on the future road network are classified as illustrated in Figure 5.3.3. The layout of East Intersection is illustrated in Figure 5.3.4.

The project road is planned to intersect with the local road at Sta. 0+806.897. However, it is undesirable to install an at-grade intersection in viewpoint of road safety and negative social impact. Therefore, a box culvert with a vertical clearance of 2.5 m, due to limits of vertical alignment, is planned under the project road of the intersection.

Table 5.3.3 Location of At-grade Intersections

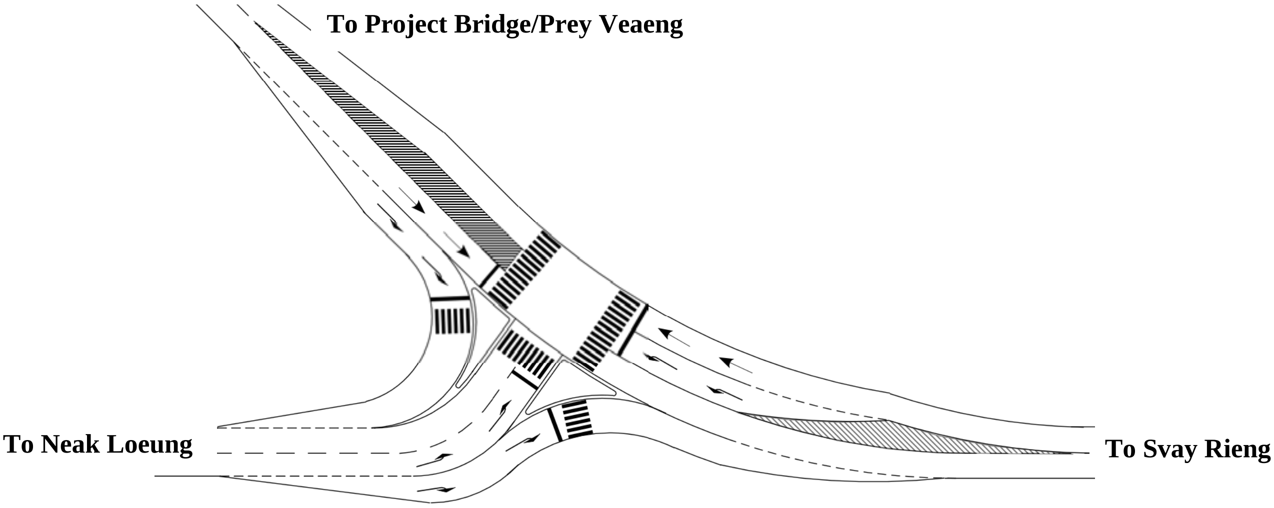
No.	Station	Name of Intersection	Type of Intersection	Classification of Intersecting Roads
1	Sta. 0+294.707	West Intersection	Channelized	Arterials (Project road) - Arterials (Existing NR-1)
2	Sta. 0+610.884	Intersection-1	Ordinary	Arterials (Project road) - Locals (Planned Service Road)
3	Sta. 1+343.408	Intersection-2	Ordinary	Locals (Planned Service Road) - Locals (Existing Road)
4	Sta. 2+553.027	Memorial Park Intersection	With Auxiliary Lane	Collectors (NR-11 Bypass) - Collectors (Existing NR-11)
5	Sta. 4+029.878	Toll Gate Intersection	With Auxiliary Lane	Arterials (Project road) - Collectors (NR-11 Bypass)
6	Sta. 4+521.873	Intersection-3	Ordinary	Arterials (Project road) - Locals (Existing Road)
7	Sta. 5+281.881	East Intersection	Channelized	Arterials (Project road) - Arterials (Existing NR-1)

Note : Station denotes the value on the project road.
Source: JICA Study Team



Source: JICA Study Team

Figure 5.3.3 Location Map of Classified Intersections with Future Road Network



Source: JICA Study Team

Figure 5.3.4 Layout of East Intersection

(3) Traffic Control Method at Major Intersections

Traffic control method is studied for major 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 unsignalized intersection. As the result of the study, all the intersections on the project road are recommended to apply the unsignalized TWSC (Two-Way Stop-Controlled) method. The detailed study process is described in Appendix 5.3.

5.3.6 Road Structure

Since the project road is located at the basin of the Mekong River, road structures are examined to secure the sufficient strength against the flood of the Mekong River in their engineering designs.

(1) Embankment Body

The project road is required to function not only as the river embankment, but also as the international road. Both embankments are expected to be long bearable and indestructible against the flood. In addition, it is necessary that the pavement of the river embankment should prevent the floodwater from permeating into the embankment body, especially the flood-free area. Therefore, the mixture materials of sand, silt and clay is generally used as a material of the river embankment, because it is expected for the cohesive soil have a small permeability.

However, the cohesive soil is avoided to use for the road embankment as much as possible, because it causes settlement. Moreover, the possibility of the cohesive soil borrowed near the study area including the dispersive clay described in Section 2.3.2 is high. If the soil is applied to the road embankment without any countermeasure, it might cause the settlement and the slide of the embankment. As for the road embankment, the soil material with not uniform grading such as gravel soil, sandy soil and so forth is preferable.

It is assumed that filling material for subgrade and embankment is brought from borrow pits on a small hill away from the study area at 10 km in the direction of the Vietnamese border. The small hill consists of granites and grano-diorite of the Mesozoic, and the residual soil of borrow pits is estimated as a silty sand with gravel or a sandy silt with gravel excluding a clay.

Taking account of the above conditions, it is proposed to use a different material between the outside and inside of the embankment. As for the inside of the embankment, namely the embankment body, a silty sand with gravel or a sandy silt with gravel brought from the borrow pits away from 10 km should be adopted. As for the outside of the embankment, namely the embankment slope, the mixture of sand, silt and clay material brought near the study area are applied after improvement by some countermeasures.

(2) Embankment Slope

As for the embankment slope, the cohesive soil is applied. It is poor in resistance against erosion due to the fine particles, the uniform grading and the low congelation. On the other hand, flow velocity is estimated at 2.04 m/s, which is described in Section 2.3.2, after the construction of the project bridge. This is slow compared with the flow velocity of 2.53 m/s around the Kizuna Bridge. Therefore, the vegetation covered on the surface of the slope such as sodding and seeding is proposed as same as the Kizuna Bridge. As for the method to protect against the floodwater, it is widely used and familiar to Cambodia. And, it is sufficient to secure the resistance against erosion in general. In addition, it is proposed that the cement is mixed with the material brought near the study area as the countermeasure against the dispersive clay.

Consequently, the cement treated soil covered with vegetation is recommended for the embankment slope of the project road.

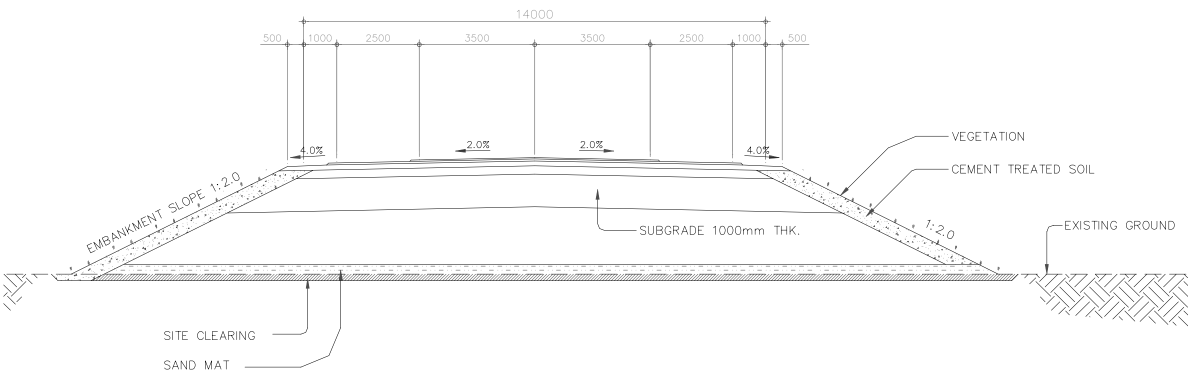
(3) Embankment Bed

The study area consists of deposit of the Mekong River and exposes soft ground. As one of the soft ground treatment against settlement which is described in Section 5.3.10 in detail and comprehension, sand mat is adopted. It plays a role of the drainage layer which discharges the water seeped out of the soft ground to outside the embankment body. Moreover, it is useful to secure the trafficability for traveling of the construction vehicles such as bulldozer and macadam roller during the construction.

The sand mat is expected to provide the following functions:

- Acceleration of the settlement
- Interception the water from the soft ground before breaking into the embankment body
- Acceleration of discharge the rainwater, if it break into the embankment
- Securing the trafficability in construction stage.

The proposed road structure is illustrated in Figure 5.3.5.



Source: JICA Study Team

Figure 5.3.5 llustration of Proposed Road Structure

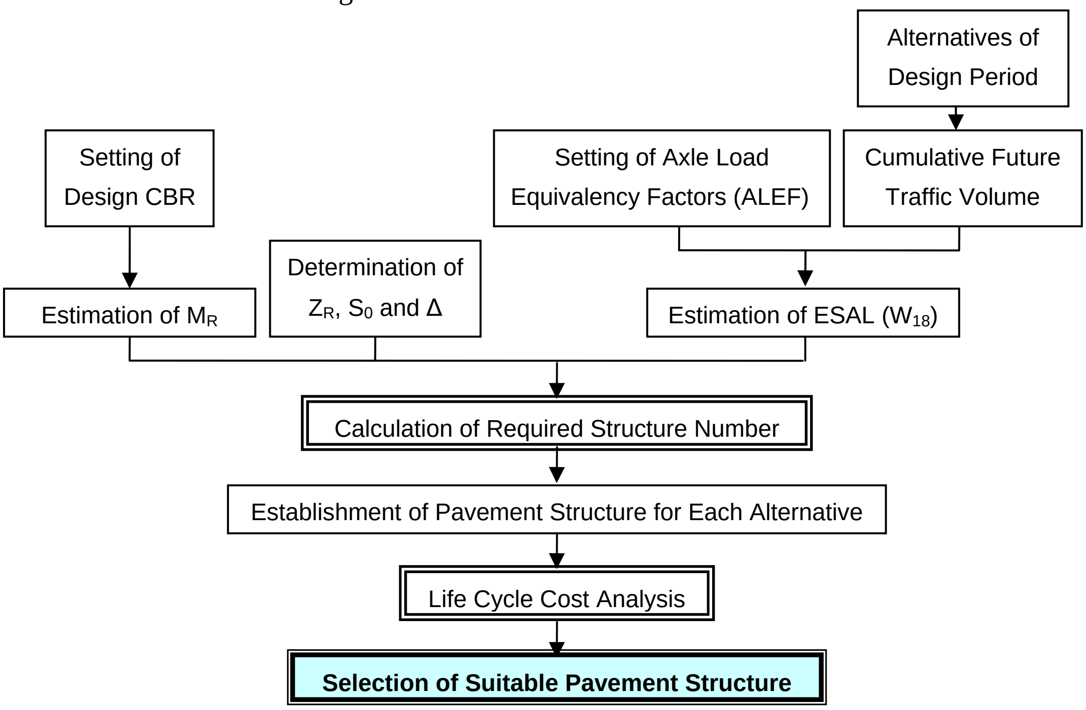
5.3.7 Pavement of Main Road

(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 5.3.6.



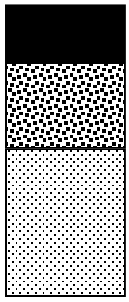
Source: JICA Study Team

Figure 5.3.6 General Flow of Pavement Design

(3) Proposed Pavement Structure

Based on the analytical process for the suitable pavement design, required pavement structure is determined as shown in Table 5.3.4. Detailed discussions on the process are exhibited in Appendix 5.3.

Table 5.3.4 Comparison of Pavement with Adjacent Section

Project		Study Section
Cumulative ESAL		$2.67x10^6$
Design CBR		7
Pavement Structure		
Thickness (cm)	Surfce Course	10.0
	Base Course	15.0
	Subbase Course	26.0
	Total	51.0
Material	Surfce Course	AC
	Base Course	Granular Material
	Subbase Course	Crusher-run

*: 50% is used for Heavy Direction Ratio.
Source: Prepared by JICA Study Team

5.3.8 Drainage

Drainage is generally divided into two types: namely, the surface drainage and the crossing drainage as described as below.

(1) Crossing Drainage

Securing the existing water flow and not being disturbed by constructing the road structure, the crossing drainage should be installed. There is small valley between the natural levees geographically located around Sta. 0+450, and a small waterway for irrigation; it traverses the road alignment. Therefore, to secure the function of waterway, the pipe culvert is planned to install in the location.

On the east bank of the Mekong River, the flood-free area is planned by the road construction. The crossing drainage does not exist except for three pipe culverts with flap gate for the purpose to drain rainwater from the flood-free land.

Locations and specifications of the planned pipe culverts are described in Section 5.3.12.

(2) Surface Drainage

The surface drainage secures to properly discharge rainwater outside the road so as not to stay long and not destruct the road.

Since there is no such obstruction as the mounted sidewalk, rainwater naturally flows outside the road, and road surface drainage is basically unnecessary. Flat ground of maximum 100 m width will be constructed between the project road and NR-11 bypass for the toll management office and other toll gate facilities. A U-shape ditch with cover should be installed at the fringe of this area. Rainwater gathered by the ditch is discharged to the flood-free area side through a pipe culvert in order to enhance the function as levee. The vertical drainage is necessary for the outlet side of the pipe culvert for the purpose of the slope protection. The step of 1.5 meter or less in width should be covered by concrete to prevent the slope from erosion.

The V-shape ditch (triangular channels) should be installed at the toe of the embankment for the purposes below:

- to lead rainwater to the pipe culvert of the crossing drainage
- to protect from erosion
- to enhance the soft ground settlement
- to accommodate the water seeped out of the sand mat and surface water discharged along the road surface or the slope or vertical ditch temporarily.

5.3.9 Toll Facilities

Since there is an alternative to operate the Project as a toll bridge with a barrier-type toll plaza, relevant toll facilities are planned as explained below. Design Guideline of Japan Highway Public Corporation is adopted as the design criteria for the Study.

(1) Review of Toll Facilities in Cambodia

National Road No.4 constructed by US Aid in 1995, is the toll road, and there are some toll facilities. The number of lanes is three by direction, and each lane is dedicated specially for a tourist vehicle, a lorry and a motorcycle as shown in Photograph 5.3.1. Toll tariff, however, consists of two type vehicles; toll from the motorcycle is not collected. Therefore, two toll booths by direction are provided.

Toll plaza is undivided by direction, and a bump is installed in a place away enough from the toll gates. Vehicle load and height scales from the bump at some distance are provided.

A. Front View of Toll Gate

B. Vehicle Classification

Source: JICA Study Team

Photograph 5.3.1 Toll Gate on NR-4

(2) The Number of Lanes

The required number of lanes at the toll plaza is calculated, based on the traffic volume, the necessary service time for collection of toll fee and the service level of vehicle queue. Accordingly, the cars that arrive one after another are generally treated under the “queue”. The simple model equation is given as follows:

$\rho = b / a$

With: ρ = Traffic strength

a = Average stock interval (sec)

b = Average service time (sec)

The result of calculation based on the above equation is tabulated in Table 5.3.5. Design condition of service time is assumed as 8 sec.

Table 5.3.5 No. of Lanes, Service Time and Capacity of Toll Gate

Unit: Vehicle/hour

Service Time / Service Level / No. of Lanes	8 Sec	
	1.0	3.0
1	230	340
2	640	780
3	1,070	1,230
4	1,500	1,670
5	1,940	2,120

Source: Japan Highway Public Corporation

On the other hand, design condition for the calculation of traffic volume is assumed as follows. The result of calculation is tabulated in Table 5.3.6

- Design Target Year: Year 2025
- Peak Hour Ratio: 12.0%
- Heavy Direction Ratio: 56.5%
- Type of Vehicle: Light Vehicle and Heavy Vehicle

Table 5.3.6 Design Hourly Traffic Volume

Items	LV	HV	Total
ADT (veh/day)	5,184	917	6,101
DHV (veh/hour)	351	62	414

Source: JICA Study Team

When the service level is assumed to be 1.0 vehicle, the necessary number of lanes is two by direction. If the lane is dedicated according to the type of vehicle such as NR-4, the toll collection system becomes inefficient due to the demand imbalance of light and heavy vehicles. Therefore, it is proposed to collect the toll fee without dividing the vehicle type. However, one lane only for the motorbike by direction is provided and physically divided from other vehicle lanes from the viewpoint of traffic safety. The toll fee is also planned to be collected from motorbikes as described in Section 6.4.

(3) Layout of Toll Plaza

Layout of the toll plaza is prepared based on Japanese Guideline referring to NR-4 as the practice in Cambodia. The lane width of the vehicle lane is adopted as 3.0 m for the inner lane and 3.5 m for the outer lane. The lane width of the motorbike is provided as 2.5 m. The toll island and toll booth are installed to the left of the lane.

Cement concrete pavement is applied due to high resistance against rutting and oil leakage. Fences and the lightings of high mast type should be prepared for security. The recommended layout plan and cross section are illustrated in Figure 5.3.7.

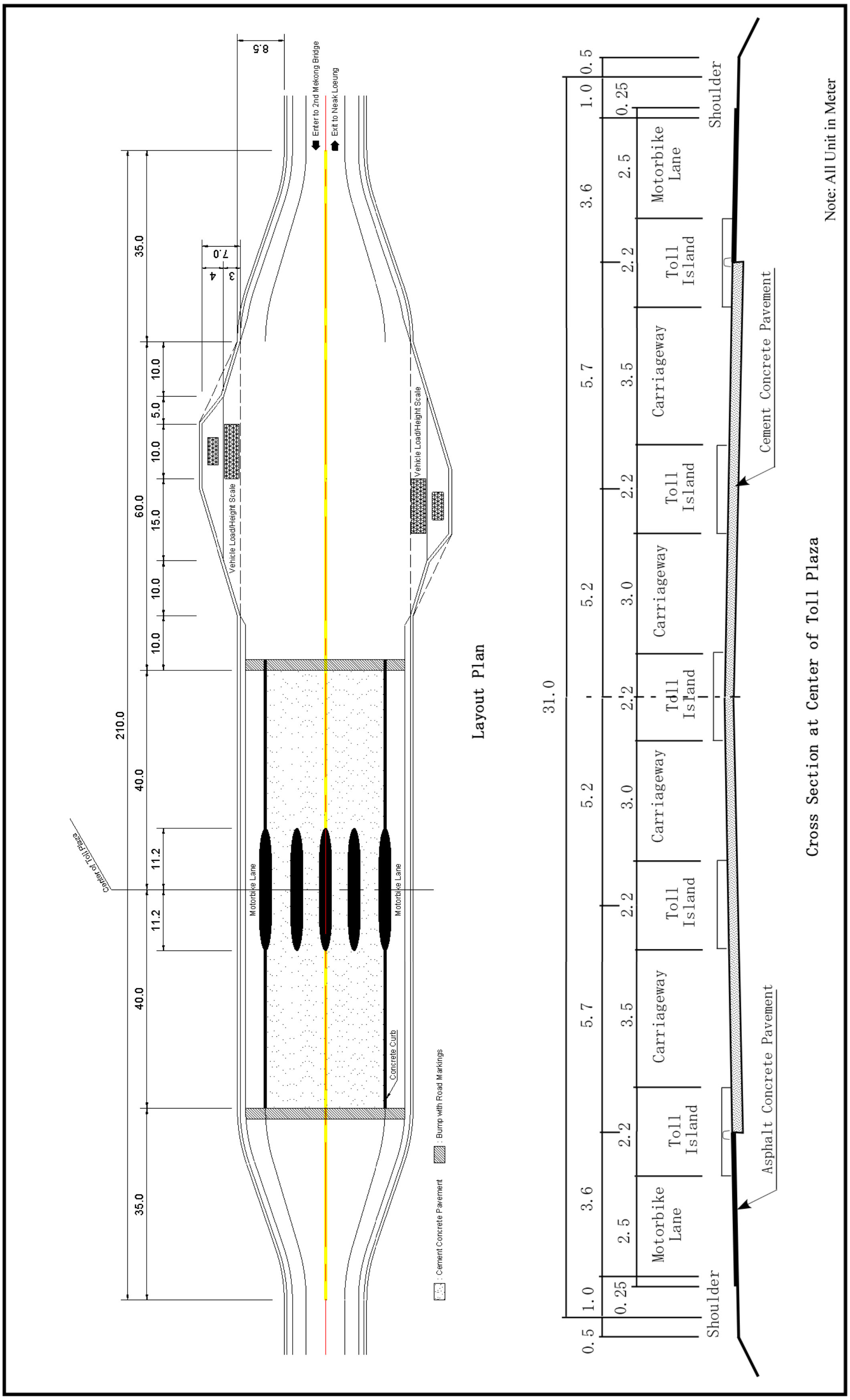
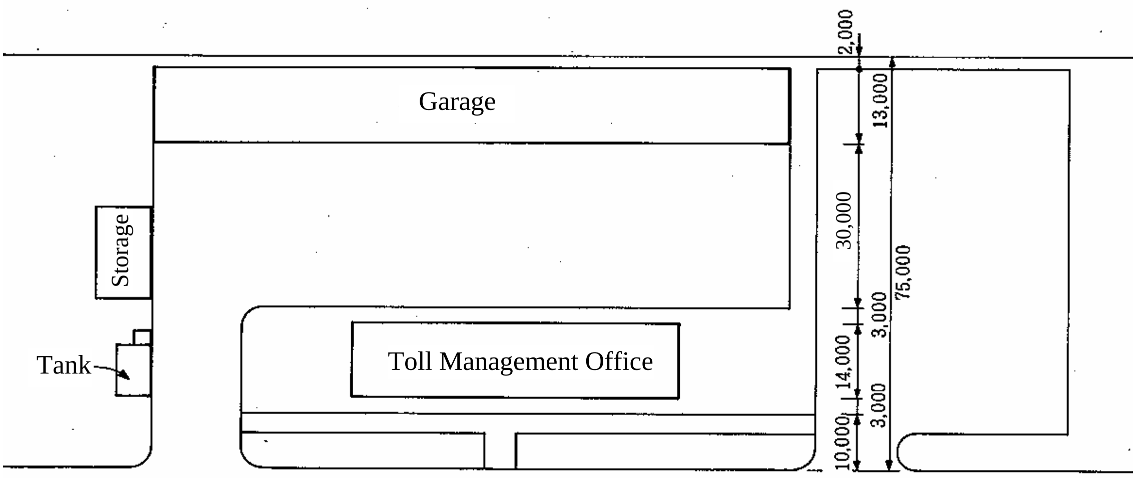


Figure 5.3.7 Layout of Toll Plaza

Source: JICA Study Team

(4) Toll Management Office

The location of the toll management office is planned to the west side of the toll plaza. Flat ground, therefore, is required between the toll plaza and NR-11 bypass. Although it depends on the operation and maintenance system, it is desirable to secure an area from 7,000 to 13,000 sq.m. Figure 5.3.8 shows a sample layout of the toll management office.



Source: Japan Highway Public Corporation

Figure 5.3.8 Sample Layout of Toll Management Office

5.3.10 Road Safety and Road Management Facilities

The objectives of the road safety and road management facilities are to maintain smooth and safe traffic flow as well as ensure the benefits of road users. The following facilities are proposed to be installed at effective locations.

(1) Safety Measure on Bridge

- Ramble strips (size W 350 x B 80 x H 9~12 mm in 150 mm Intervals)
- Centralized road markings (size W 300~450 mm)
- Color pavement (size H 10 mm)

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

(2) Traffic Signs

- Regulatory and Warning Signs
- Guide Signs

(3) Road Markings

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

(4) Other facilities

- Kilometer Posts
- Guard Posts
- Road Lightings
- Road Studs

5.3.11 Soft Soil Treatment for Embankment

(1) Stability and Settlement of Consolidation of Road Embankment

According to the geological survey, soft grounds from 6 to 17 m in thickness exist in the project area. Height of embankment is 4.0 to 8.0 m and it is necessary to study the stability and consolidation settlement for embankment.

1) Stability of Embankment

The heights of critical filling are shown in Table 5.3.7.

Table 5.3.7 Height of Critical Filling

Location	C (tf/m^2)	Qd (tf/m^2)	Γ (tf/m^3)	Height of critical filling (H=qd/γe)	Planed (H)	Safety factor (=H'/H)
Sta.0+100-0+700	3.2(AC1)	16.7	1.8	9.23m	4m	2.31
Sta.3+100-4+300	3.2(AC1)	16.7	1.8	9.23	8m	1.17>1.2
Sta.4+300-5+200	4.5(ACH)	22.9	1.8	12.7	8m	1.58

Note: qd (=5.1C): critical bearing capacity, C: cohesion(qu/2), qu: unconfined compressive strength, γ e: unit weight
Source: Japan Road Association

It is necessary to take some countermeasure works for road embankment at Sta. 3+100-4+300 where safety factor is less than 1.2. There are some methods for solidification of soil for the stability of embankment such as Sand Compaction Pile Method, however, costs of these methods are high. On the other hand, Step Filling method and Counterweight Filling method are simple and inexpensive. Counterweight Filling method has following benefit and is recommended for the project. Scope of Counterweight Filling is shown in Table 5.3.8

- Construction Term for Step Filling method is long.
- Good filling materials are available
- Right of way for approach road is wide
- Construction method is simple
- Counterweight filling can construct same time with main embankment

Table 5.3.8 Scope of Counterweight Filling

Location	Station	Width	Length	Height	Earth Work
Left bank of Mekong River	Sta.3+060～Sta.4+300	17m	1,240m	2m	(1,240m+250m)x17mx2m = 50,660m^3
Transition area to temporary road	Sta.B1+450- Sta.4+300	17m	250m	2m	
Height of temporary road should be less than 7m.					

Source: JICA Study Team

2) Countermeasure for Consolidation Settlement

Surcharge Fill is commonly used for consolidation settlement because of its cost advantage and simplicity. However, the duration required to achieve the desired consolidation is too long where the layer of soft soil is very deep. One of the most effective ways to accelerate the Consolidation Settlement is providing artificial paths for excess pore water in the ground to seep out. Vertical drain is one of the methods to let excess pore water in the compressible soil seep out. The vertical drain consists of series of boring fill with sand or cardboard. The cardboard drain is recommended because the construction cost of sand drains is higher than the card-board wicks. In case that improvement soft soil is not carried out at approach road area, and continuous maintenance such as over lay of the pavement shall be required, because settlement will progress little by little for a long time. Consolidation settlements at locations of soft soil are shown in Table 5.3.9.

Table 5.3.9 Consolidation Settlement at Location of Soft Soil

Location	Layer	H (m)	γ' (tf/m^3)	ΔP (kgf/cm^2)	Po (kgf/cm^2)	Cc	e_0	Sc (cm)	Cv (m^2/s)	T (U_{80})	Rs (cm)
Section 1 Sta.0+100 -0+700	AC1	4.0	1,724	0.72	0.35	0.621	0.621	64	5.066 x10^{-7}		
	AC1	2.0	0.724	0.72	0.73	0.621	0.968	19			
		6.0	Total					**83**		**4 months**	18
Section 2 Sta.3+100 -4+300	AC1	5.0	1.806	1.41	0.4	0.128	0.850	22.0	8.28 x10^{-8}		
	AO1	4.0	0.365	1.38	0.88	0.649	2.477	30.5	3.45 x 10^{-8}		
	AC2	7.0	0.443	1.35	1.11	0.407	1.855	33.8	4.07 x10^{-8}		
	AO2	1.0	0.404	1.27	1.28	0.528	2.166	5.1			
		17.0	Total					**91**		**>40 years**	17
Section 3 Sta.4+300 -5+200	ACH	4.0	1.970	1.44	0.35	0.35	0.766	51.1	1.489 x 10^{-7}		
	AO1	5.0	0.702	1.38	0.82	0.82	1.024	21.5	4.7065 x 10^{-7}		
	AC2	2.0	0.443	1.3	1.04	1.04	0.407	9.8	4.07 x10^{-8}		
	AO2	3.0	0.404	1.27	1.14	1.14	0.528	16.3			
		14.0						**99**		**>11 years**	20

Note: Sc : Depth of Consolidation settlement (cm), T: Duration for 80% of final settlement
Source: JICA Study Team

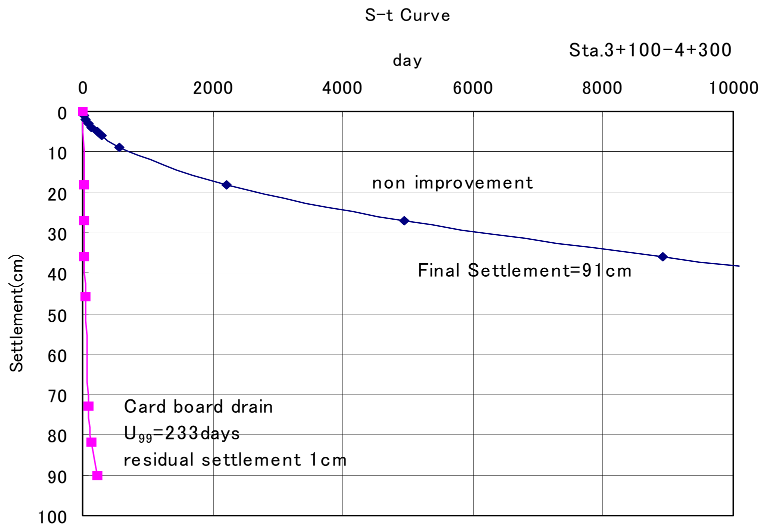
Scope of Cardboard Drain Method and consolidation settlement after the improvement are shown in Table 5.3.10, and settlement and time curve (before and after improvement) are show in Fig 5.3.11.

Table 5.3.10 Scope of Cardboard Drain Method and Consolidation Settlement

Location	Depth (m)	Spacing (m)	Length (m)	*Time for U99%(day)*	S(cm) U99%	Rs (cm)
Right bank: abutment of pier Sta.0+760-0+860 :	6	1.2 square type	16,128	38	82	1
Left bank: abutment of pier Sta.3+080-3+180, B.0+500-0+450,	17		93,534	23	90	1
Left bank: toll gate Sta.3+650-4+110 B.1+050-B.1+450	14		489,522	41	98	1

Note: U99 : Consolidation degree is 99%, S: Settlement at U99, Rs: Residual settlement (Final settlement)-(S)
Source: JICA Study Team

The effect of the soft soil improvement by the Cardboard Drain method at the location between Sta3+100 to Sta4+300 is shown in Figure 5.3.9.



Source: JICA Study Team

Figure 5.3.9 Consolidation Settlement Curve at Sta3+100 to Sta4+100

5.3.12 Protection of Embankment

Local construction materials, equipment and labor shall be utilized for the river bank protection facilities. The objective of river improvement works is not only to protect river bank but also to create "nature-friendly rivers" to develop an attractive environment, i.e. beautiful natural landscape. "Specification of River Facilities: Japan River Association, 1998" has been applied as the design standard for the river facility for this Study.

(1) Embankment

The earth embankment is not always durable against overtopping by flood waters, therefore adequate freeboard should be designed to reach above the high water level, considering the wave, swell, splash and floating debris. The height of the embankment should be designed adjusting to the high water level (7.8 meters MSL) plus freeboard (0.5 meter) in general. In addition, the embankment of the approach road should be designed with full consideration of connection of the existing road. Table 5.3.11 shows the elevation of crossing points of the proposed road. The side slope of the road embankment is usually protected by vegetation (sod facing), but the additional protection works should be considered along the road sections, especially where the flood water directly affects. Requirements for river banks and that for the road embankment are shown in Table 5.3.23.

Table 5.3.11 Elevation of Crossing Points

	Location of Crossing Points				
	NR-1 (C-1)[3]	Right Levee	NR-11[4]	PR-101	NR-1 (C-2)[5]
Proposed Route	9.0		8.4	-	8.2

Source: JICA Study Team

[3] Basic Design Study Report on the Project for Improvement of NR-1 in Kingdom of Cambodia, October 2004, JICA
[4] Emergency Rehabilitation of National Roads 11,ADB Loan No.1824 CAM(SF), Part A-Southern Region, Drawings for Contract S-07R11c-1, Bidding Documents Volume III, December 2001, MPWT
[5] Greater Mekong Subreagion Infrastructure Development, Ho Chi Minh City to Phnom Penh Highway Improvement Project Contract No C2, Bidding Document Volume III, September 1998, MPWT

Table 5.3.12 Requirement for River Bank and Road Embankment

Item	Requirement for River Bank	Road Embankment
Slope Angle	1 : 2.0 or milder	1 : 2.0
Compaction of Embankment Soil	85% of maximum density obtained from laboratory compaction test or higher	90% or more
Type of Soil	Mixture of sand, silt and clay (ideal)	Mainly fine sand ad silt with clays
Slope Protection	Vegetation	Vegetation
Width of Embankment	5 meters or wider	

Source: JICA Study Team

Sandy materials are preferable as the sub-grade material for the embankment because of its bearing capacity, while cohesive materials such as silt and clay are preferable for resistance against water penetration. Sandy materials and cohesive materials shall be mixed to use for the embankment.

If materials for embankment are properly compacted and utilized such as 90% or more of maximum dry density obtained by the laboratory compaction test, this type of soil is considered to have sufficient resistance against the erosion. According to the “Ordinance for River Related Structures” of Japan (ORRSJ), materials with 85% or more compaction shall be utilized for the embankment of the riverbank, since the compacted soil is expected to have small permeability (in the order of 10^{-6} cm/s or less). Soil with permeability k of less than 10^{-6} cm/s is considered practically impervious in general. the relationship between the type of soil and permeability is shown in Table 5.3.13.

Table 5.3.13 Characteristics of Permeability of Soils

Permeability K (cm/s)	Drainage	Soil Types
10^{2}	Good	Clean gravel
10^{1}		
10		Clean gravel, clean sand and gravel mixture
10^{-1}		
10^{-2}		
10^{-3}		Very fine sands, organic and inorganic silts, mixtures of sand, silt and clay, glacial till, stratified clay deposits, etc.
10^{-4}	Poor	
10^{-5}		
10^{-6}	Practically Impervious	
10^{-7}		Impervious soils, e.g., homogeneous clays below zone of weathering
10^{-8}		
10^{2}		

Source: “Soil Mechanics in Engineering Practice”, K.Terzaghi and R.B.Peck, 1967

(2) Vegetation

The slopes of existing NR-1 road are fairly well protected against flood water and vegetation is widely used for the slope protection at the river banks. To help growth of grasses on the newly constructed slope, it is proposed to place the topsoil collected from the nearby waste land. These topsoil are expected to contain seeds and roots of the grasses which grow in the area along the proposed embankment, and is thus considered to be adequate for the environment of the study area. If a green belt is set up within slope of the embankment to prevent the flow of floodwater, the erosion by the flood is expected to be reduced.

(3) Revetment

Revetment shall be formed on a bank/embankment to prevent erosion. Various materials can be utilized to form the revetment, including turf, sheets and concrete blocks connected by wooden piles, bush wood, gabion, stone and concrete blocks.

In case the velocity of the flow is lower than 2.0 m/s, vegetation such as turf can sufficiently prevent erosion from the water flow. Wooden piles and brush wood with stone filling are used to protect embankment from the flood and they provide places for plant growth and shelter for small animals and fish in the cavities in the revetment. The same function can be expected by placing natural stone. Sheeting and netting cover the bank slope increase the strength from erosion by the water flow and improve the environment for the plant.

Concrete blocks can strongly protect the embankment against the water flow, however, the installation of concrete blocks has some problems from the environmental viewpoint. The type of such revetments should be limited only under some circumstances such as scale of erosion of river is fairly large. The maximum velocity of flow of Mekong River at Neak Loeung is estimated less than 2.0 m/s and the maximum velocity of flow along the proposed embankments is estimated less than 1.2 m/s through the hydraulic analysis in this Study. Considering the velocity of flow, revetment by vegetation is recommended for the protection of the embankment at this study area.

The several types of the revetment are nominated as follows:

1) Reed Planting

The stems of reeds are planted on the river bed along the banks. As reeds spread naturally into an opening, additional planting is seldom required. Root nets and rootstocks of reed at a depth of about 30 cm prevent soil erosion. The rapid growth of reeds makes the flow velocity slow down and prevents sedimentation on foot of bank. This method is recommended to apply where the river bed is shallow and composed of fine sand to gravel and the flow velocity is low.

2) Planting of Willow Cutting

Planting of willow cutting is recommended for the areas where fluctuation of the water level is within 60 cm in depth and above the low water level. The material of the bed composed of fine sand to cobble stones is preferable. This method combined with other conventional methods will protect the banks for a long time.

3) Planting of Tree*s*

Root systems of tress tightly hold the ground and protect the river banks. This method is recommended for areas where the bed is composed of fine sand to pebbles and the water depth is less than 50 cm. Tree-planting in the banks protect bank for many years with a good environment. The trees along the river bank improve the environment of the area providing shade for living space. As trees have positive impacts on life in river and offer shelters for fish. Several years will be necessary to make these positive impacts to occur by this method.

4) Wire-Mat and Rip-rap

These methods are generally applied for the protection of slope of the embankment and it is applied to the protection of the embankment at National Road No.11 near proposed route.

This method is used for not only protection of levee but also foot protection works. Rip-rap protection has many practical examples and should be recommended as protection measures.

5) Foot Protection

Foot protections are recommended to stabilize the foundation of a river bank. The component of foot protection shall be determined taking into consideration of the velocity of flow, the property of river bed materials and fluctuations of river bed including local scouring. Meanwhile, the extent of the foot protection shall be planned to accommodate the width of structures constructed in the bank and shall have enough width against the expected maximum scouring. Foot protection shall be flexible enough to follow the variation of river bed and shall withstand the water flow to avoid rapid scouring. Foot protection shall have enough width to prevent settlements of the foundations in front of the revetment of bank. As foot protection has a function of shelter as well as feeding place for fish, etc., there should be sufficient water depth above these bases. In addition, porous materials and components which provide many cavities in the foot protection is recommended. It is necessary to harmonize foot protection works with the site conditions and foot protection works with porous nature and flexibility such as wooden submerged bed with riprap type are recommended. 15 cm of riprap size will be recommended for the project site, considering the flow velocity is below 3.0 m/s.[6]

(4) Forest along the River Bank

A forest along the river bank protects the bank from erosions and improves the environment of surrounding area. The trees in the forest along the river bank or waterside formed proper circumstance for flora and fauna and supply feeding place for fish and other aquatic fauna. The Mekong River discharges itself into Mekong flood plain and the wave of water flow collides with road embankment in flood season. The forest along river bank also expects to work for the protection from flood waves.

5.3.13 Flood-free Area Protection

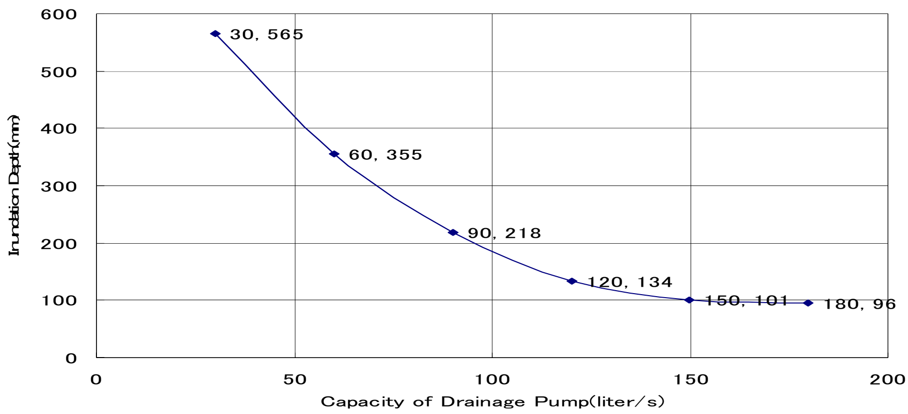
(1) Water level at the Flood-free Area

NR-1, NR-11 and embankment of approach road in this Study, create about 100 hectare of flood-free area. It is considered as the closed area without any opening to outside the area, so that the drainage of the water from inside to the outside the area shall be studied. The water level of the flood-free area is estimated by the difference between rainfall and evaporation at the area. Maximum water level in the flood area has been calculated with Meteorological data[7] and the maximum water depth is estimated at about 100 mm.

(2) Drainage System at Flood-free Area

The estimated water level by the rainfall in the flood-free area is small and a small-size water pump is enough to drain water in the area. The necessary capacity of the pump to drain water inside the flood-free area is about 120 to 150 liter/sec. This amount could be handled by 4 or 5 portable water pumps. Pipe culverts with flap gate are recommended to be installed in embankment for drainage pumps. Relation between water depth in the flood-free area and capacity of drainage pump is shown in Figure 5.3.10.

[6] Design of Revetments and Gabions, Sankaido, June 2003, Koichi Yamamoto, Japan
[7] Data of Meteorology in 2001-2003, Department of Water Resources and Meteorology, Prey Veng Office of Meteorology and Hydrology.



Source: JICA Study Team

Figure 5.3.10 Water Depth and Capacity of Drainage Pump

Facilities for protection of embankment from river flow are summarized in Table 5.3.14.

Table 5.3.14 Summary of the Protection Works for River Flow

Location	Present Condition	Measures and Works	
Sta.0+450	Trace of old river remains and water way at the flood time shall be kept.	Drainage and irrigation water may be necessary at the downstream of the approach road. Culver should be installed at bottom of approach road and entrance of culvert should be protected by stone masonry.	<u>Culvert</u> Type: Pipe Material: Concrete Pipe ϕ 600mm x 2, L=75mx1
Sta.0+900	Tributary between NR. No.1 and Phnon Knong Island. Both side of tributary are gently slope in to the river and vegetation is rampant. No erosion was observed at right side bank of tributary. The vehicle could pass across the tributary in dry season.	Piers are constructed near the slope of tributary. Trace of erosion by wave and flow are observed at left side of the tributary. Protection works is not required at right side of tributary.	<u>Revetment</u> Type: Wire mat filled rip rap Stone: 15cm Size:1m x 2m x 0.50m Slope :1:3.0 B=50m, L=11m
Sta. 1+825	Right side of bank of Mekong River is a perpendicular cliff There are many parts showing erosion wave flow.	Piers are constructed near the slope of river and protection for the pier is inevitable.	<u>Revetment</u> Type: Wire mat filled rip rap. Size:1m x 2m x 0.5m Stone: 20cm Slope :1:2.0 B=50m, L=13m
Sta.2+475	Left side bank of Mekong River (NR.No11) The bank has gradual ascent. Parts of erosion were not observed. NR.No.11 is along levee of left bank.	Piers are constructed near the slope of river. Some protection work for the pier shall be installed.	<u>Revetment</u> Type: Wire mat filled rip rap. Size:1m x 2m x 0.5m Stone: 20cm Slope :1:4.0, B=50m, L=14.3m
Sta.4+050 Sta.4+500 Sta.4+950	Flood Plain between NR, No11 and Stueng Slout River. Ground level is 2-5 m MSL and water level depends on the water level of Mekong River.	Drainage system from flood-free area shall be installed.. Drainage by movable pumps is recommended..	<u>Pipe Culvert</u> Type: Pipe with flap gate Material: Concrete Pipe ϕ 600mm x1, L=17mx3

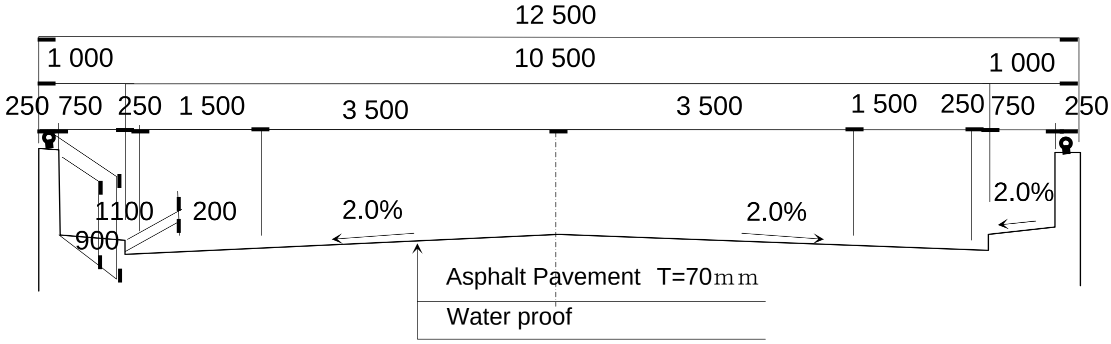
Source: JICA Study Team

5.4 Bridge Design Criteria and Standard

5.4.1 Bridge Design Conditions

(1) Width of Bridge

The bridge length is 2.2 km which is too long for pedestrians to walk through the bridge, therefore the footpaths for pedestrians are not planned on the Bridge. However, inspection ways for the safety of bridge inspectors and emergency evaluation shall be provided in the bridge width. Consequently, the width of the bridge is recommended as shown in Figure 5.4.1.



Source: Prepared by JICA Study Team

Figure 5.4.1 Roadway Width on the Bridge

(2) Navigation Channel Layout

The navigation channel Layout definitively affects the safety of vessels that pass under the bridge and consequently the size of the navigable vessel. It is also influential to determine overall bridge layout, optimal bridge type and construction costs.

1) Vertical Clearance

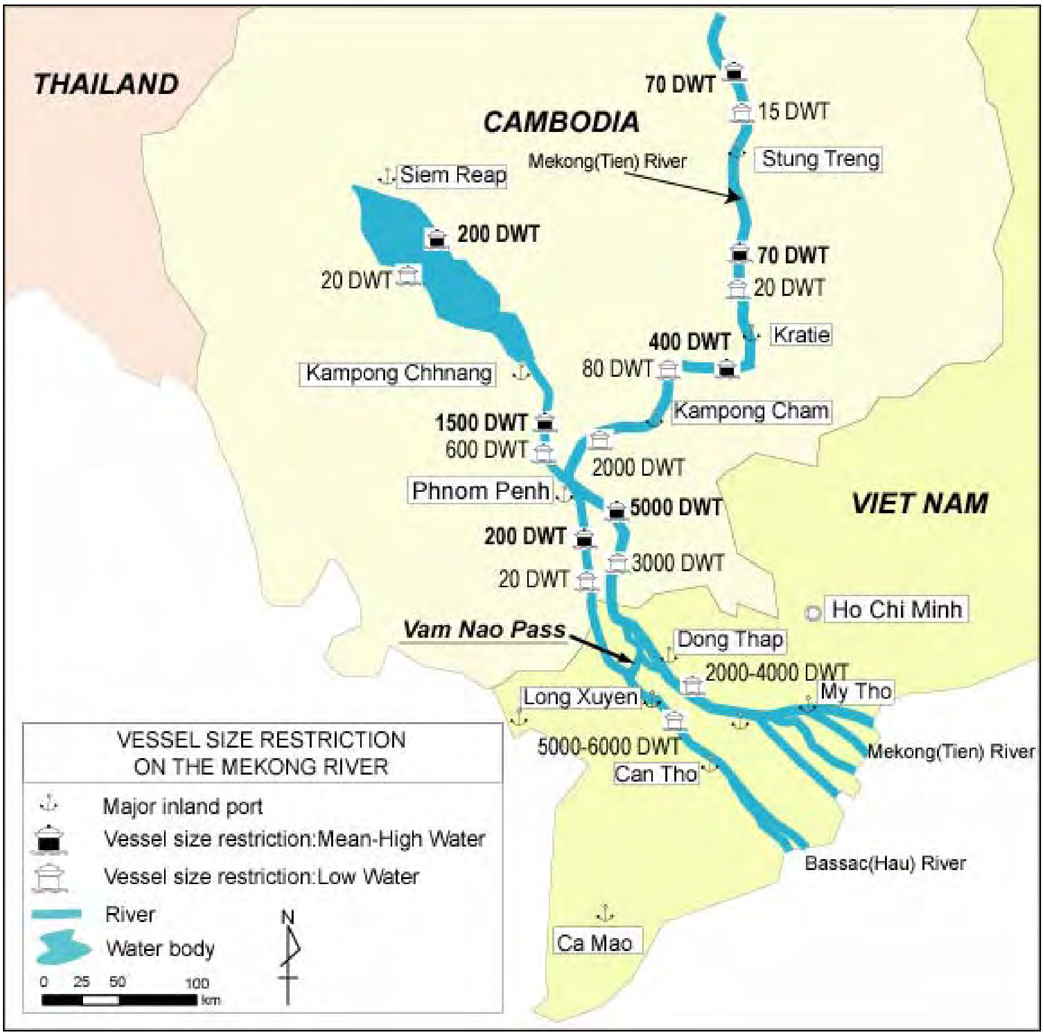
The vertical clearance of the navigation channel is determined based on the following conditions:

a. External Conditions

- My Thuan Bridge crossing the Mekong River in Vietnam was completed in May 2000.
- The vertical clearance of My Thuan Bridge is 37.5m. This clearance was requested by the Cambodian government to the Vietnamese government.
- Can Tho Bridge with the vertical clearance of 39.0 m is under construction to cross the Hau River in Vietnam. The clearance allows 15,000 DWT vessels to enter Can Tho Port.
- Generally, a 5000 DWT vessel and a 3000 DWT vessel are navigable up to Phnom Penh through the Hau River in Vietnam and the Mekong River in Cambodia at a Mean-High water and a Low water, respectively (see Figure 5.4.2).

b. Development Policies and Plans in Cambodia and Mekong River

- Containerization is in a rapid progress at Phnom Penh Port, and the Phnom Penh Port Autonomous plans to construct an Inland Container Depot near the Port. 5000 DWT container ships are anticipated to enter the Phnom Penh Port .
- An MRC official stated formally that the navigation clearance of the Bridge at Neak Loeung should be 37.5 m at the Stakeholder Meeting held on 7th of October 2004 to ensure "Freedom of Navigation" for the Mekong River as agreed by the member countries in the article 9 of the agreement.
- The World Bank plans to dredge the mouth of Hau River to enable vessels enter to Mekong River system from the sea. 5000 DWT container ships should be able to navigate the Mekong River system up to Phnom Penh Port.



Source: State of the Basin Report 2003, Mekong River Commission

Figure 5.4.2 Vessel Size Restrictions on the Mekong River (Cambodia and Viet Nam)

c. Mast Height of the Vessel

The height of the bridge is determined by the mast height of the vessel which passes under the bridge and also the high water level of the river. Mast heights of several kinds of ship were studied in the Technical Note No.714 June 1991 of the Port and Harbour Research Institute of Ministry of Transport Japan. Based on the data from the report, the mast height of the 5000 DWT container ship could be determined as 36.0 m. The mast height of container ship is estimated by the regression analysis and the formula is presented as follows:

$$Y = aX^{b} + e$$

where;
- Y : Mast height (m)
- X : Tonnage of the Ship (DWT)
- a, b : Parameters from the regression analysis
- e : Constant

Table 5.4.1 Mast Height for Several Kind of Ships

		Passenger Ship		Oil Tanker		Container Ship	
		Year 79	Year 90	Year 79	Year 90	Year 79	Year 90
a		2.725	4.790	4.829	3.741	7.840	4.268
b		0.279	0.209	0.192	0.214	0.166	0.224
e		5.498	7.883	12.53	12.776	3.568	4.642
X	50,000	61.265	53.847	51.083	50.670	50.812	52.814
	10,000	41.091	40.718	40.835	39.629	39.735	38.233
	5,000	34.833	36.290	37.308	35.927	35.804	33.402

Source; Technical Note No. 714 of the Port and Harbor Research Institute Ministry of Transport, Japan

Considering the allowance to be 1.5 m for the safety over the mast height, the vertical clearance of the navigation span of the bridge is planned to be **37.5 m.**

2) Horizontal Clearance

A horizontal clearance of the navigation span decisively influences the safety of vessel navigation, and it should be as wide as possible from the safety point of view, but confined within the allowable extent of technical and economic justification. The traffic density of large vessels at Neak Leung is assumed not to be so high, and so the navigation channel under the bridge could be operated by one-way traffic, while that of small vessels might be so high in future that the channel should be operated by two-way traffic. For two-way operation, the maximum size of the small vessel should be controlled.

Based on the "Technical Standard for the Port Facilities", Ministry of Transport, Japan, April 1999 and the "Ship Domain" theory in the report of "SHIP COLLISION WITH BRIDGES, IABSE, AIPC, IVBH 1993", the required horizontal clearance guideline is as shown in Tables 5.4.2 and 5.4.3, and Figure5.4.3 illustrates the requirement of the horizontal clearance.

Table 5.4.2 Vessel Profiles

Type of Vessel		Ship Length (m)	Breadth (m)	Draught (m)
5000 DWT	Cargo Ship	109	16.8	
	Oil Carrier	102	16.8	
	Container Ship	103	15.4	
700 DWT	Cargo Ship	57	9.5	3.4
500 DWT	Coaster	51	9.0	3.3

Source; Technical Standard for the Port Facilities, Ministry of Transport, Japan, April 1999.

Table 5.4.3 Technical Criteria for the Horizontal Clearance of Navigation Span of the Bridge

<table>
<tr><th>Source</th><th>One Way</th><th>Two Way</th><th>Note</th></tr>
<tr><td rowspan="5">Technical Standard for the Port Facilities, Ministry of Transport, Japan</td><td>Waters with low traffic density : H.C.＞0.5L</td><td>Waters with high traffic density : H.C.＞ 1 L</td><td>In case H.C.＜1L, safety measure such as navigation aid system shall be settled.</td></tr>
<tr><td colspan="3">a) In case long navigation route: 1.5L</td></tr>
<tr><td colspan="3">b) Open sea situation with high traffic density: 1.5L</td></tr>
<tr><td colspan="3">c) Long navigation route with high traffic density: 2.0L</td></tr>
<tr><td colspan="3">In case of navigation route with special condition such as high traffic density include crossing vessel, super large vessel or severe natural conditions, horizontal clearance shall be wider than the standard.</td></tr>
<tr><td rowspan="2">Ship Collision with Bridges (IABSE)</td><td>3.2L</td><td>6.7L to 8.2L</td><td>Free Navigation (at service speed)</td></tr>
<tr><td>1.6L</td><td>3.5L to 5.0L</td><td>Restricted Waters
(With pilots or Vessel Traffic Service System)</td></tr>
</table>

Note: H.C.: Horizontal Clearance, L: Ship length
IABSE: International Association for Bridge and Structural Engineering
AIPC :Association of Intenationale des Ponts et Charpentes
IVBH: Internationale Vereinigung für Brückenbau und Hochbau

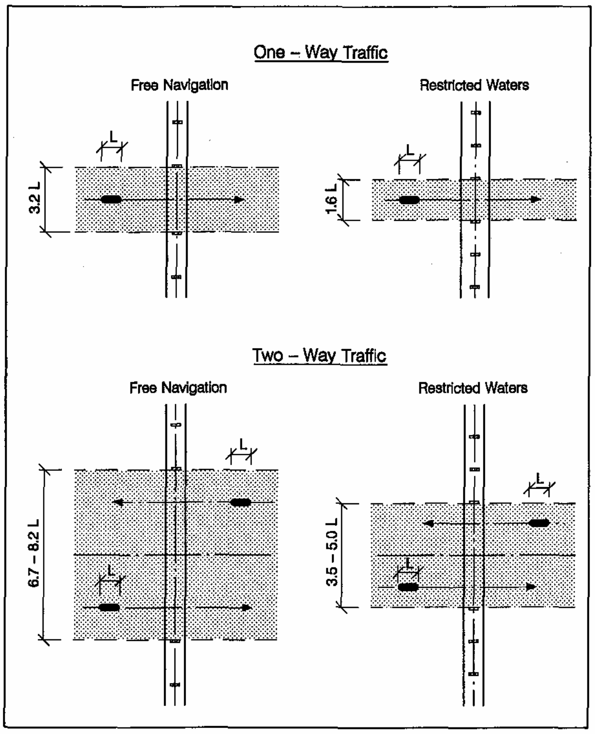
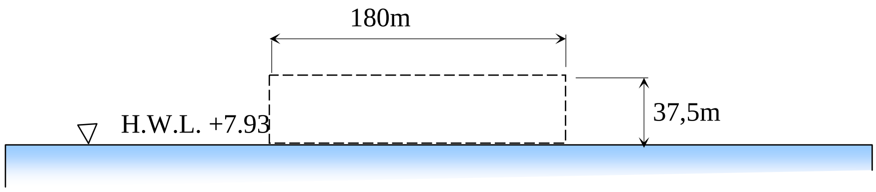


Figure 5.4.3 Horizontal Clearances by Ship Domain Theory

Consequently, the minimum clearance of the navigation channel for the Second Mekong Bridge is recommended as shown in Table 5.4.4.

Table 5.4.4 Recommended Navigation Channel Layouts

	One way traffic	Two Way traffic
Vessel Size	5,000DWT Container Ship	500DWT Coaster
Horizontal Clearance	B=1.6 x L =175 < 180m Where, L : Ship Length = 109m	B= 3.5 x L =179 < 180m Where, L : Ship length = 51m
Vertical Clearance	37.5m	37.5m
Minimum Clearance of Navigation Channel		

Source and Note: Horizontal Clearance is calculated by the Ship Domain analysis in the Ship Collision with Bridges issued by IABSE, AIPC and IVBH

5.4.2 Design Criteria and Standard

Standard Specifications of American Association of State Highway and Transportation Officials (AASHTO) is applied to the design of road and bridges on National Highway No.1 in Cambodia improved by the Asian Development Bank and the B/D study by JICA. However, the AASHTO Standard is in the process of change to a new Standard, and AASHTO clearly indicates the following:

There are two AASHTO Standards, i.e. the long standing AASHTO Standard Specifications for Highway Bridges and newly adopted AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specification. Eventually, the Federal Highway Administration (FHWA) and the states in the United States of America have established a goal that LRFD standard be incorporated in all new bridge design after 2007.

Thus, AASHTO Standard Specification for Highway Bridges is now in transition to the newly established LRFD, and which means that details of LRFD are not fully specified or practicable to the reality like the long standing AASHTO. In addition, either AASHTO or LRFD are applicable to ordinary highway bridges, but not satisfactory for a special bridge such as the Second Mekong Bridge with main span length exceeds 200 meters.

In Japan, various long-span bridges with main span exceeding 200 m have been designed to apply the Design Standard that had been elaborated by Honshu-Shikoku Bridge Authority. This Design Standard is based on the Japanese Design Standards. Kizuna Bridge was also designed by the Japanese Design Standards. Therefore, it is recommended that the Japanese Design Standards will be applied to the Project as the design standard for the Bridge.

(1) Dead Load

Dead load shall be applied in accordance with Japanese Design Standard Articles concerned. The unit weight of the dead load is shown in Table 5.4.5

Table 5.4.5 Unit weight of the dead load (kN/m3)

Material	Unit weight	Material	Unit Weight
Steel	77.0	Concrete	23.0
Cast iron	71.0	Mortar	21.0
Aluminum	27.5	Timber	8.0
Reinforced Concrete	24.5	Bituminous	11.0
Pre Stressed Concrete	24.5	Asphalt Pavement	22.5

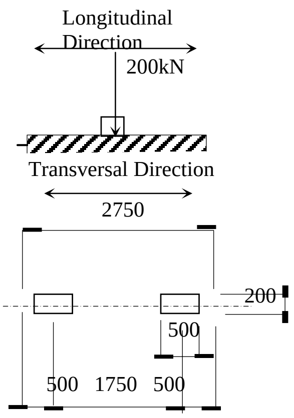
Source: Standard for highway bridge published by Japan Road Association

(2) Live Load

A-Load (TL-20) was applied to the design of KIZUNA Bridge. However the Second Mekong Bridge is located on the Asian Highway Route AH-1 and the 2nd East-West Economic Corridor, connecting Bangkok-Phnom Penh-Ho Chi Minh. Since many heavy vehicles such as big trailers shall pass on the bridge, B-Load of the Japanese Standard for Bridge Design that allows a big trailer weight as live load for the bridge, and which eventually is adopted for the design of the Second Mekong Bridge.

Table 5.4.6 T-Loading (Wheel Load)

T-Loading



Design for the floor system	L≦4	4<L
	1.0	L/32+7/8
	L: Span Length	

Source: Standard for highway bridge published by Japan Road Association

Table 5.4.7 L Loading (Uniform Load)

L Load (Uniform Load)							Sub Load
Main Load（5.5m width）							
Load	Uniform Load P1			Uniform Load P2			
	Loading Length D (m)	Load (kN/m^2)		Load (kN/m^2)			
		For Bending moment	For Sharing Force	L≦80	80<L≦130	130<L	
B-Load	10	10	12	3.5	4.3-0.01L	3.0	50% of Main Load

Source: Standard for highway bridge published by Japan Road Association

Table 5.4.8 Impact by the Live Load

Bridge Type		Impact Coefficient
Steel Bridge		I =20/50+ L
Concrete Bridge	For T-Loading	I = 20/50+L
	For L-Loading	I = 10/25+L

Source: Standard for highway bridge published by Japan Road Association

(3) Water Pressure

1) Water Level and Water Velocity

The high water level with a return period of 100 years and the low water level with a return period of 20 years at the bridge construction site are adopted for the design of the bridge.

Table 5.4.9 Water Level and Water Velocity

H.W.L.	M.S.L.+7.93m(Return Period of 100 years)	
L.W.L	M.S.L.+0.43m(Return Period of 20 years)	
Discharge and Velocity	Max	Q = 33,000 m^3/s, V_{max}=2.0 m/s
	Min	Q = 3,000 m^3/s, V_{min}=0.5 m/s

Source: JICA Study Team

2) Water Flow Pressure

Water flow pressure occurs to the structure in the river at the project area and it is calculated by the following formula:

$$P = K * V^2 * A$$

Where;

P: Water flow Pressure (T)
K: Resistance Coefficient of pier determined by the shape of the structure.
V: Maximum Water flow velocity (m/sec)
A: Projected area of Structure in the river (m^2)
H: Water Depth (m)

(4) Vessel Collision

The vessel collision forces are taken into account for the design of bridge foundation and they are shown in table 5.4.10. Vessel size, collision velocity and collision load are based on the criteria of "Ship Collision with Bridges, IABSE, AIPC, IVBH 1993".

Table 5.4.10 Vessel Collision Force

Items	Design Condition	Remarks
Vessels as object	5,000 DWT	
Collision velocity	2.25 m/sec	Average flow velocity of Mekong river + drift velocity of vessel 1.0m/s
Collision load	20MN(for reference)	

Source: JICA Study Team

Safety against the entire failure of foundation shall be studied against vessel collision, but partial damage of foundation is not considered. In case Vessel Collision would affect the collapse of the foundation, Anti-Collision facilities should be studied.

(5) Wind Velocity

Based on the data from 1985 to 1995 at the observatory on Kampong Chum, (Ministry of Agriculture) and data from 2001 to 2003 at the observatory on Pray Veaeng (MRCS), the maximum wind velocity adopted to the design of bridge shall be V=30 m/sec.

(6) Temperature Variation ,

Lowest and highest temperature from 2001 to 2003 is 16℃ and 38℃ respectively and it is adequate to consider the temperature variation from 15℃ to 40℃ for the bridge design..

(7) Seismic Coefficient

A large scale earthquake has not been recorded in Indochina Peninsular in the past as reported in Interim Report (March,2005) and according to Achie Bridge design data near Neak Loeung, The seismic coefficient is determined as follows:

K_h=0.05 and Kv=0.0

(8) Scoring Depth Considered in Design

Scouring of riverbed occurs around the foundation, if the foundation of the bridge is constructed in the river. The scouring around the foundation would cause decreasing of bearing capacity and horizontal resistance of foundation and could have fatal influences on the foundation. Some formula will be applied for the design of foundation and another method will be applied for scouring protection works for foundations. In case of large scale foundation, the scouring protection does influence the construction cost. In case of Kizuna Bridge, masonry scouring protection works were effective and negligible scouring was observed after completion of the bridge construction. The scorings were not considered for the design of foundation with the premise that appropriate scouring protection measure will be taken.

5.5 Selection of Bridge Type

5.5.1 Introduction

The optimal bridge design concepts along the selected route are discussed in this chapter. Technical issues regarding the bridge construction on the selected route are studied to provide the information for the feasibility study of the Project. Selection of an optimal bridge type will follow the procedure as illustrated in Figure 5.5.1 and each of the steps is discussed in the following sections.

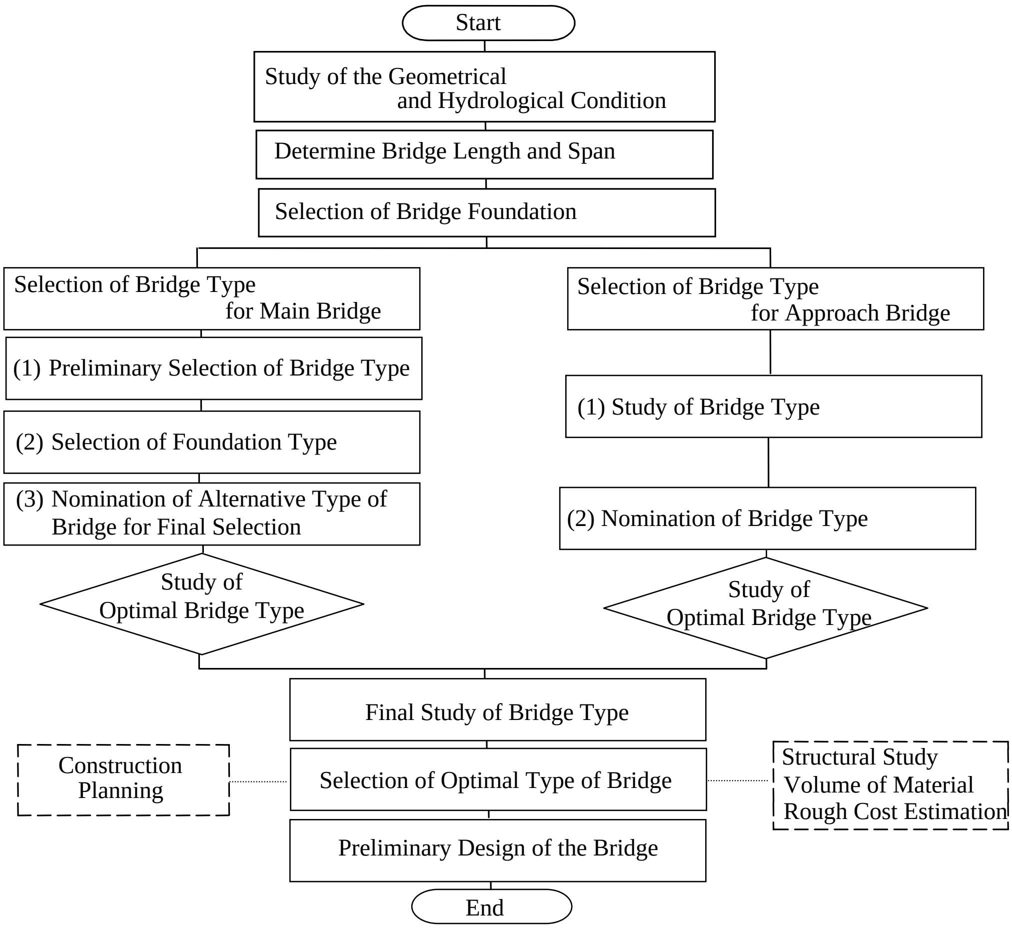


Figure 5.5.1 Flow Chart of Selecting Optimal Bridge Type

5.5.2 Geological and Hydrological Conditions

Prior to the selection of an optimal bridge type, the road alignment along the selected route was examined and fixed as stated in Section 5.3.3. Three additional drilling works were implemented along the planned alignment, and this information is reported in detail in Section 2.3.2 of this report. According to the boring survey, basement rock was not found at any additional drilling holes. However, diluvial layers that have enough strength to support the bridge foundation are found at around 60 m below the ground level.

The bridge construction site at Neak Loeung is located at downstream of Tonle Sap Lake which alleviates the fluctuations of the water level because of its function as a natural reservoir. Accordingly, the difference between HWL and LWL at Kampong Chum is 14.54 m, while that at Neak Loeung is 7.5 m.

Flooding at Neak Loeung records 1.96 m/sec of water velocity, while the hydrodynamic simulation estimates a 2.04 m/sec by MIKE 11 in case the bridge will be constructed at the selected Route-A. Therefore, 2.04 m/sec is recommended as a velocity of the floodwater for designing the bridge.

5.5.3 Bridge Length and Span Length of Main Bridge

(1) Bridge Length

Total bridge length for this project is determined by the following factors:

1. Horizontal alignment of the approach bridge.
2. Gradient of vertical alignment of the approach bridge.
3. Highest elevation of the bridge.
4. Geographical condition at the selected route.
5. Girder height of the approach bridge and height of embankment in relation with the ground height and substructure.

1) Elevation of Abutment

The elevation of the abutment is determined from girder height of the approach bridge and height of embankment in relation with the ground height. Based on this data, road elevation at the abutment position is calculated as EL+12.5m.

2) Determination of Bridge Length

According to the vertical alignment of the road, EL+12.5m position should be Sta.No. 0+875 m in the right bank side, Sta.No,3+095 in the left bank side and the bridge length should be L=2,220 m. The bridge length will change due to further investigations in the future.

(2) Span Length of the Main Bridge

The navigation width and the size of pile cap of the pier of the bridge shall be taken into account to determine the span length of the main bridge. The minimum horizontal navigation width shall be 180.0 m for 5000 ton ships which pass under the bridge and the width of pile cap of the bridge will be 30.0 m; therefore, the expected span length will be 210.0 m.

5.5.4 Bridge Foundation

(1) General

Evaluation criteria for the selection of optimum type of foundation for the project Bridge are as follows:

1. Overall bridge planning
2. Geographical condition of the construction site
3. Geological condition
4. Condition of the river
5. Aesthetic viewpoint

(2) Basic Design Condition

1) Overall Bridge Planning

“Route-A” with the total length of 5.4 km including approach road is selected as the optimum route of the project. A height of the bridge is determined by the condition of river navigation on the Mekong River and considering the gradient of the approach road. The bridge section will start from Station No. 0+875 and end at Station No.3+095. The total bridge length will be 2,220 m.

2) Geographical Conditions

Geographical conditions of the construction site in relation with the selection of foundation type are shown in Table 5.5.1 and Figure 5.5.2.

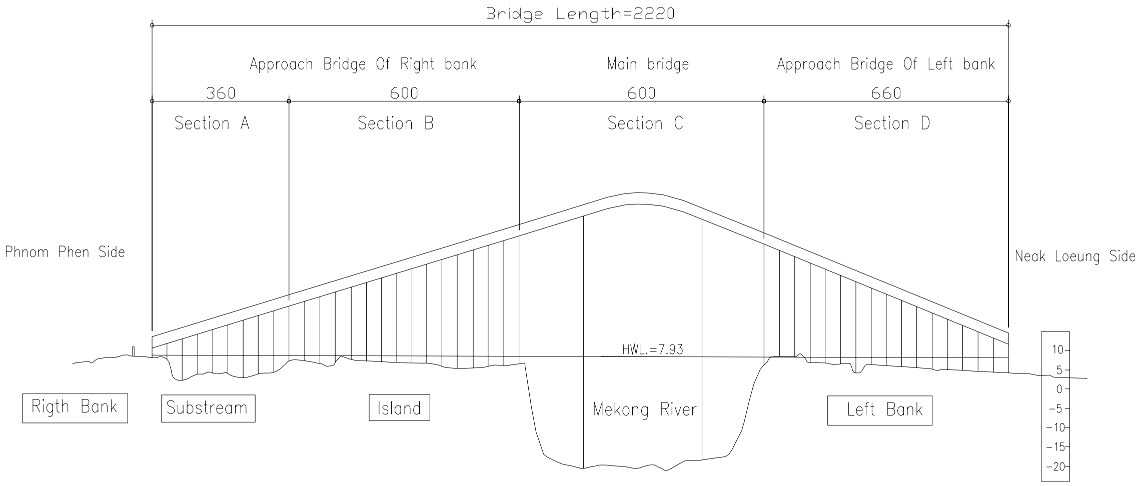


Figure 5.5.2 Bridge Sections Classified by Geographical Conditions

Table 5.5.1 Bridge Sections Classified by Geographical Conditions

Section	Bridge Section (Station No.)	Length of Section	Geographical Conditions
A	0+875m～ 1+235m	360m	Bridge crosses over the tributary of the Mekong River. Height of riverbed of the tributary is around 3.0m and passable by vehicles in dry season.
B	1+235m～ 1+835m	600m	This section is sand bank of the Mekong River and average ground height is 6.0m. The flood does not submerge the area around 8 months a year.
C	1+835m～ 2+435m	600m	Bridge crosses the Mekong River in this section including section D for main bridge and section C and E for approach bridge. Average depth of the riverbed is about 20.0m and maximum depth of the river is approximately 28m.
D	2+435m～ 3+095m	660m	This section is in the swamp area, which lies in the left side of the riverbank and the ground height varies from 4.0m to 6.0m. The approach road and construction road are planned in this area. The flood does not submerge the area around 6 months a year.

3) Geological Conditions in Bridge Construction Site

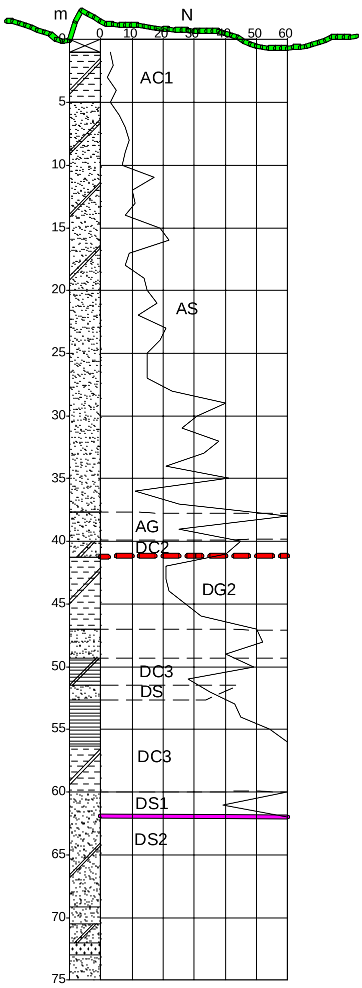
Two drilling surveys (NBH-6, NBH-7) were carried out in the bridge section along “Route-A” as introduced in Section 2.1. Summary of the geological conditions at each drilling point is as follows:

a. NBH-6

In this area, there are quaternary deposits consisting of alluvial and diluvial unconsolidated sand and clay. Sand with gravel of 3.0m thick is found at the depth of 39 m and 48 m. The consolidated diluvial sand with SPT value over 30 is found at the depth of 49 m. The silty sand and sandy silt with SPT value over 60 are found at the depth of 56 m. This sandy silt is considered as a bearing stratum for the foundation of the bridge. The soft alluvial clay is found on topsoil and horizontal movement and negative friction for the foundation shall be studied around this area. Boring log map for NBH-6 is shown in Figure 5.5.3

b. NBH-7

In this area, there are sandy silts of 4.0 m thick on topsoil and quaternary deposits consisting of alluvial silty clay with sand to the depth of 36 m. Sandy silt, Sandy Silty Clay and gravel of 1.0 to 5.0 m thick are found at the depth over 36m. Soft clay with SPT value from 0 to 5 are found at the depth of 18 m and clay with SPT value of 12 is found until the depth of 31 m. Clay with SPT value over 20 is found at the depth over 43 m. However, consolidated alluvial sand with SPT value over 60 is found at the depth 58 m and this layer would be considered as a bearing stratum for the foundation of the Bridge. Soft clay and soft organic clay are found from the top to 20 m and possibility of settlement of embankment and its influence on the foundation shall be studied carefully. Boring log map for NBH-7 is shown in Figure 5.5.4



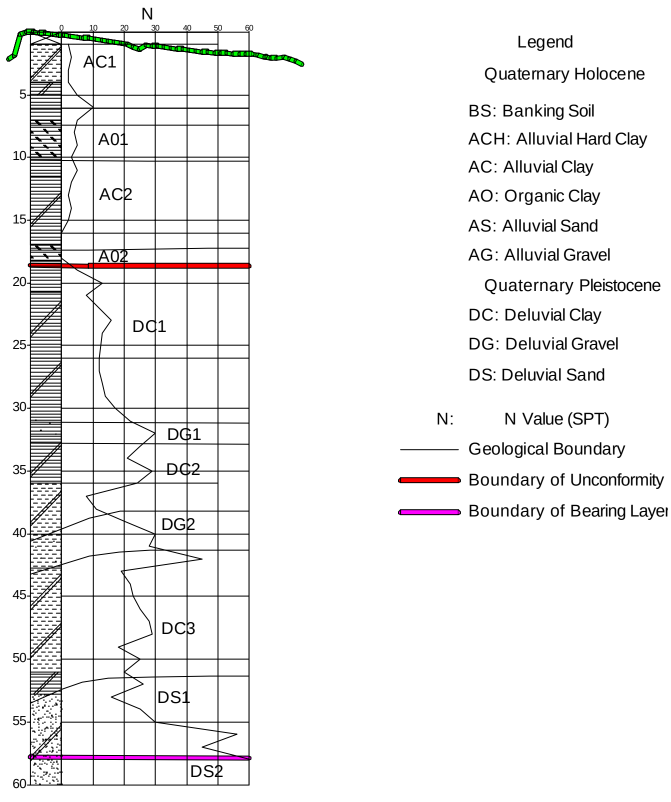


Figure 5.5.3 NBH-6 **Figure 5.5.4 NBH-7**

3) River Conditions

Based on the fluctuation of water level in the year 2000, the number of days under water at each elevation are shown in Table 5.5.2.

Table 5.5.2 Elevation and the Number of Days under the Water

Elevation (EL)	Maximum	Mean	Minimum
EL≧8m	0	0	0
EL=7	73 (20%)	49 (13.6%)	0 (0%)
EL=6	140 (38.9%)	105 (29.2%)	77 (21.4%)
EL=5	173 (48.1%)	143 (39.7%)	113 (31.4%)
EL=4	206 (57.2%)	173 (48.1%)	146 (40.6%)
EL≦3	246 (68%)	223 (62%)	208 (58%)

Selection of the type of foundation should consider the following conditions:

1. There are possibilities that seven months in the year will be submerged at section A
2. There are possibilities that four months in the year will be submerged at section B
3. There are possibilities that six months in the year will be submerged at section D

4) Study from the Aesthetic Viewpoint

The Main Bridge is the long span bridge having over 210 m of center span and it is important to plan the bridge from the aesthetic viewpoint. In the dry season, appearances of pile cap over the surface of the water will tend to mar the beauty of the scenery. Foundation should not stand out and substructure should be designed from the aesthetic viewpoint.

(3) Alternative Type of Foundation

1) Selection of Alternative Type of Foundation for the Bridge

Types of foundation that could be adopted for the Bridge are as follows:

a. Land Area (Section A, B and D)

There are many foundation types that could be adopted on land area. However, since the bearing stratum is deep and submergence of the construction area is highly possible in the rainy season, the foundation that meets the deep bearing stratum and short construction period should be selected. Reinforced cast in place pile, steel pipe driven pile and reinforced concrete driven pile should be examined as the foundation at the land area.

b. River Area (Section C)

Multi column foundation, steel pipe sheet pile foundation and steel hull caisson foundation that meets as a foundation for deep water and deep bearing stratum have been studied. Many multi column foundation types were adopted to the bridge constructed in the Mekong River such as Can Tho Bridge and Kizuna Bridge and the steel sheet pile foundation was adopted to the Japan Cambodia Friendship Bridge in Phnom Phen. It is necessary to prepare a man-made island for the caisson foundation in general and it is not practical to construct the manmade island in deep water of the Mekong River. Therefore, floating caisson has been studied as one of the alternative methods for the bridge foundation. Many floating caisson foundations for a large-scale bridge are constructed in Japan and Korea. Open caisson and pneumatic caisson are studied in case of caisson foundation.

2) Selection of Type of Foundation in Each Section

Based on the similarity in geological conditions, the sections are classified into two groups: that is A, B and D sections for one group and C sections for another. Alternative types of foundation under the similar geological conditions are compared and evaluated as presented in Table 5.5.3. As a consequence, cast in place concrete pile foundation is recommended for Section A, B and D.

Table 5.5.3 Selection of Type of Foundation for Sections A , B and D

Type of foundation / Design Condition	Pile Foundation			Multi Column		Open Caisson	Pneumatic caisson	Steel Pipe Sheet Pile
	RC Pile	Steel Pile	C.P.C Pile	Steel Pile	C.P.C. Pile			
Construction on Land	○	○	○	Not applicable				
Scale of super structure	○	○	○					
Depth of support layer	×	○	○					
Settlement, side move	×	○	○					
Construction period	○	○	△					
Aesthetics	○	○	○					
Similar achievement	○	△	○					
Cost	○	×	△					
Evaluation	×	×	1					

Note: C.P.C: Cast in Place Concrete

Multi column foundation with steel pile, multi column foundation with cast in place concrete and steel pipe sheet pile foundation are compared as alternative foundation type for Section C and evaluated as presented in Table 5.5.4. As a consequences, cast in place concrete pile foundation is recommended for Section C. General views of these alternatives are shown in Figure 5.5.5.

Table 5.5.4 Selection of Type of Foundation for Section C

Type of foundation / Design Condition	Pile Foundation			Multi Column		Open Caisson	Pneumatic caisson	Steel Pipe Sheet Pile
	RC Pile	Steel Pile	C.P.C Pile.	Steel Pile	C.P.C. Pile			
Construction in Deep Water	Not applicable			○	○	○	○	○
Scale of super structure				○	○	○	○	○
Depth of support layer				○	○	△	×	○
Durability)				△	○	○	○	△
Vessel Collision				×	△	○	○	△
Construction period				○	○	△	△	○
Aesthetics				△	△	○	○	○
Similar achievement				△	○	○	×	○
Cost				△	○	×	×	△
Evaluation				3	1	×	×	2

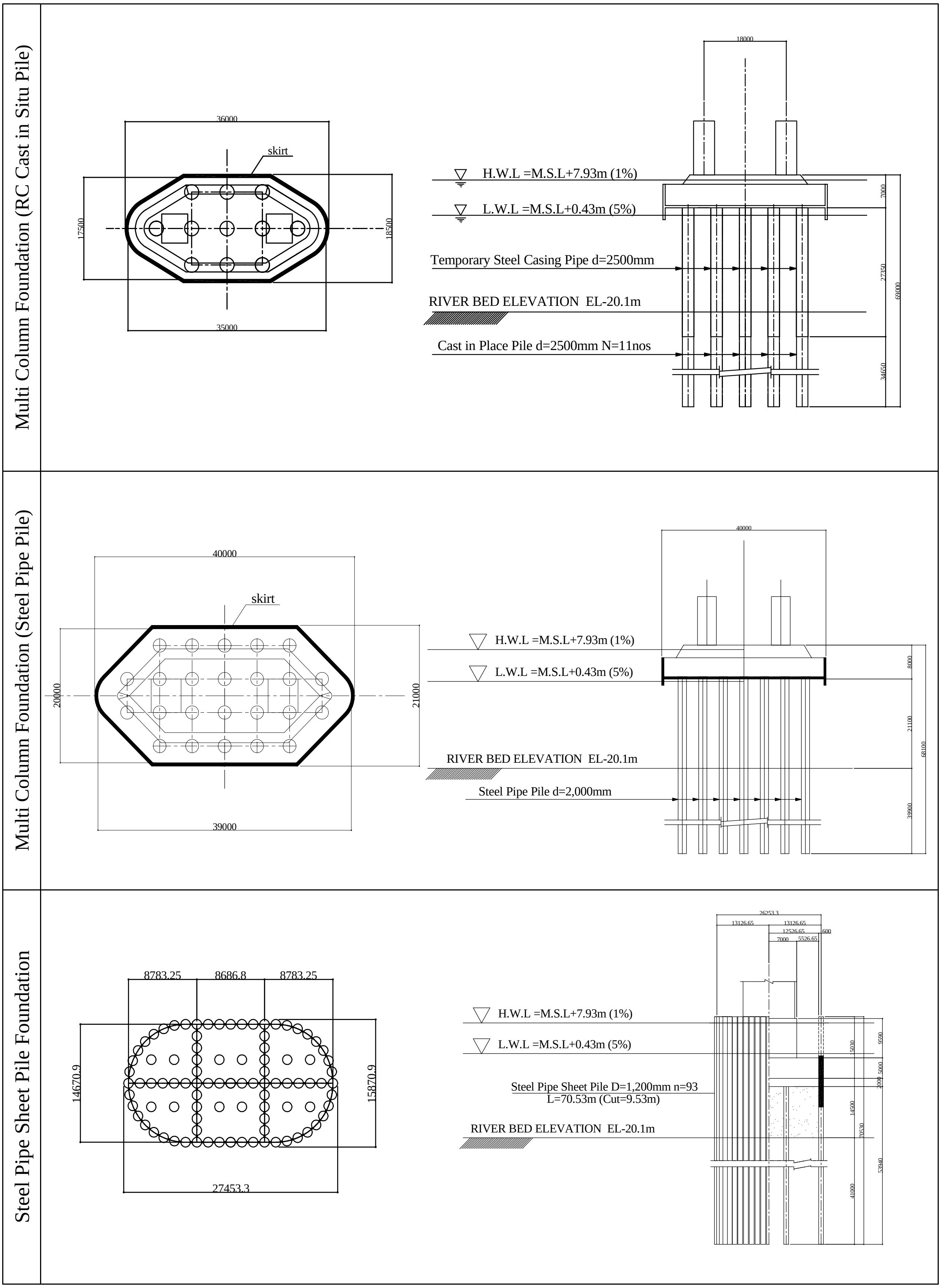


Figure 5.5.5 Foundation for Main Bridge

Table 5.5.5 Summary of Foundation for Main Bridge

			Evaluation
Multi Column Foundation (RC Cast in Situ Pile)	Construction Cost		Lowest cost among 3 alternative foundation plans **(1.00)**
	Property of Structure	Availability of domestic products	Main material is concrete. Domestic products is available
		Employment of Labor	Local labor can join many work
		Technical Transfer	Some parts such as quality control of concrete could be transferred
		Record of the structure	There are lot of record on bridges in Mekong river
	Construction	Construction term	Many kinds of work. Period is long. Specific works need in dry season
		Safety for construction	Need careful slime treatment. Precautions for the construction of foundation in the river are inevitable.
	Maintenance		Need periodical inspection for scoring of the river bed
	Aesthetic Viewpoint		Piles and Pile Cap appears above the water surface in dry season,
Multi Column Foundation (Steel Pipe Pile)	Construction Cost		Second lowest construction cost among three alternatives **(1.38)**
	Property of Structure	Availability of domestic products	Steel Pipes should be imported.
		Employment of Labor	Local labor scarcely could join the main work such as steel pile driving
		Technical Transfer	Technical transfer will be slight.
		Record of the structure	Many record in Japan but in Mekong River
	Construction	Construction term	Construction period will be short compared to other 2 alternative plans
		Safety for construction	All construction are possible from above surface of River
	Maintenance		Need management of anti- corrosion works for Steel Pipes such as electrical anti-corrosion, multi-layer anti-corrosion painting. Need periodical inspection for scoring on the river bed
	Aesthetic Viewpoint		Piles and Pile Cap appears above the water surface in dry season.
Steel Pipe Sheet Pile Foundation	Construction Cost		Construction cost is the highest among 3 alternatives **(1.98)**
	Property of Structure	Availability of domestic products	Steel Pipe Sheets should be imported.
		Employment of workers	Local labor scarcely could join the main work such as steel pipe sheet pile driving
		Technical transfer	Technical transfer will be slight.
		Record of the structure	Japan Cambodia Friendship Bridge on Tonle Sup River
	Construction	Construction term	Construction Period is longer than other alternatives. I t is possible to construct in high water of the river.
		Safety for construction	Water tightness of sheet pile shall be carefully maintained.
	Maintenance		Need management of anti-corrosion treatment of Steel Pipes such as electrical anti-corrosion, multi-layer anti-corrosion painting Need periodical inspection for scoring on the river bed
	Aesthetic Viewpoint		Foundations are constructed under water and structure is the best aesthetically among three alternatives.

(4) Selection of Approach Bridge Foundation

1) Approach Bridge Foundation

As to the Foundation of Approach Bridge, taking into account the depth of bearing stratum, Pile Foundation should be selected as described in Section 5.5.4. Furthermore, for the most suitable foundation of the Main Bridge, Cast-in-Place Concrete Pile (CPCP) is already selected, and no reason is found to use Steel-Pipe-Pile (SPP) solely for Approach Bridge. It is therefore concluded that CPCP should be selected for Approach Bridge Foundation too.

The Pile Diameter of more than d=800 mm is considered as CPCP generally. However in case the Pile length is over 50 m, a Pile Diameter more than d=1,000 mm should be selected. Among 3 alternative types of Superstructure of Approach Bridge, 2 types of Pile Diameter such as d=1,000 mm and d=1,200 mm are roughly studied including influences of Negative Friction. As the consequence, pile with diameter 1.000 mm is recommended for each type of Superstructures. The reasons to select the 1000 mm diameter Pile are as follows:

1. The scale of Superstructure is relatively small.
2. Designed horizontal seismic intensity is small
3. Depth of bearing stratum is deep and big bearing capacity could be expected.

Combination of substructure, pile foundation and superstructure for approach bridge are shown in Figure 5.5.6

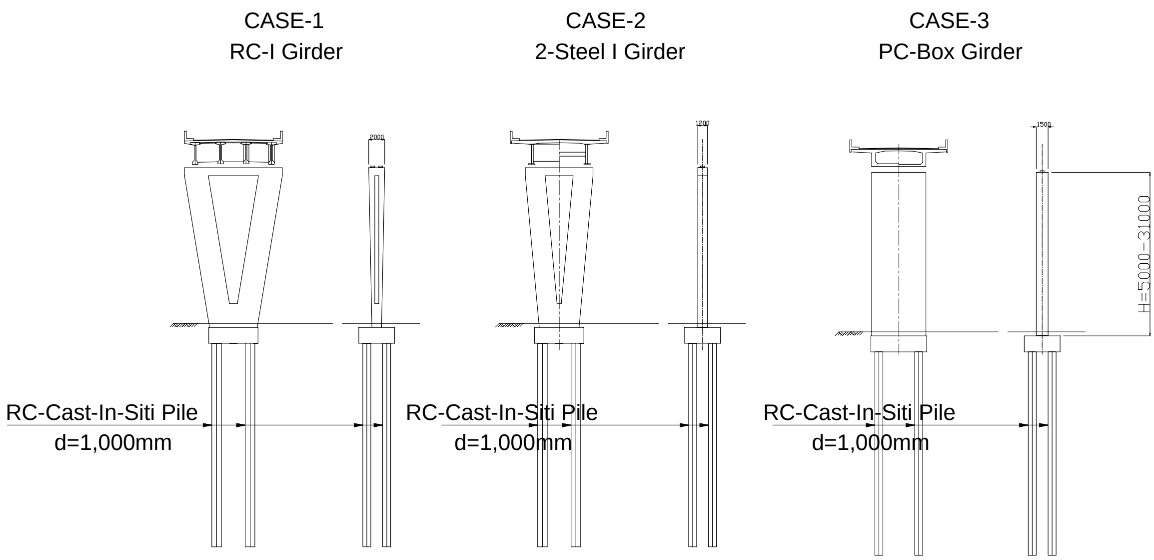


Figure 5.5.6 Approach Bridge Substructures on Land

5.5.5 Selection of Main Bridge Type

(1) Nominated Bridge Types

The minimum span length of the Main Bridge is 210 m and the number of alternative bridge types is limited to satisfy the design conditions. In this chapter, several bridge types are nominated to compare and select the optimal type of bridge for the Main Bridge. Bridge types that suit the span length of over 210 m are compared in Table 5.5.6

Table 5.5.6 Type of Bridge for Main Bridge

	Type of Bridge	Description
Steel Bridge	Continuous Box Girder	Bridges with the span length of 250m (Kaida Bridge Namihaya Bridge) exist in Japan. Orthotropic deck is adopted for this type of bridge, however the construction cost tends to be high.
	Continuous Truss	Bridge with the span length over 400m (Ikutuki Bridge) exists in Japan. This type of bridge accommodates the long span bridge, however the structure is complicated and the maintenance cost will be high.
	Trough Arch	There are many through arch bridges with the span length over 210m. However, there are some difficulty in assembling, transport and erection of the superstructure in Cambodia.
	Cable Stay	Span length of 210m is the lower limit for this type of bridge from the viewpoint of the construction cost. Orthotropic deck is commonly adopted for this type of bridge, however the construction cost tends to be high. Steel tower is commonly used in Japan, while concrete tower is common except Japan. Study to reduce the construction cost is required to adopt this type of bridge in Cambodia, considering the transportation cost of the material. Wind tunnel test is required.
Concrete Bridge	Extra-dosed (Composite)	Bridge with the span length over 210 m exists (Kisogawa Bridge L=275 m, Japan Parao Friendship Bridge L=247 m).
	Cable Stay	There are several bridges with the span length over 210 m (Ikara Bridge L=260 m, Ooshiba Bridge L=210 m, My Tuan Bridge). Any major technical problems are not found in adopting this type of bridge to the Project. Wind tunnel test is required.

As compared in Table 5.5.6, six bridge types (Continuous Steel Box Girder Bridge, Continuous Steel Truss Bridge, Steel Through Arch, Steel Cable Stay Bridge, PC Extra-Dosed Bridge and PC Cable Stay Bridge) are compared as alternative bridge types for the Main Bridge. More detailed comparison among the nominated bridge types has been carried out for the selection of optimum type of bridge for the Main Bridge as presented in Table 5.5.7. Figure 5.5.7 shows the general views of six alternative bridge types.

Comparison and selection of the optimal type of bridge among six alternative bridges types were conducted by using Analytic Hierarchy Process (AHP).

Main issues for the selection of main bridge type are as follows:

1) Construction Costs
2) Property of the Structure

The construction of the large-scale project bridge influences not only improvement of the mobility of NR-1 traffic, but also various societies in Cambodia. An appropriate bridge type should be selected considering the following evaluation sub-criteria that influence the societies in Cambodia:

- Availability of the construction material in Cambodia
- Employment of Cambodian Labor
- Technical transfer to Cambodia

Technical assurance and similar achievement of the bridge type in the past shall be taken into consideration for the selection, and the following additional sub-criteria are adopted for the selection of bridge type:

- Past record of the construction of the bridge type
- Technical assurance and stability of bridge construction at the site condition.
- Adequacy for the natural environment at the construction site.

3) Construction Method

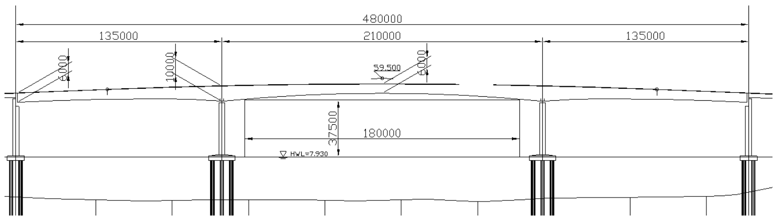
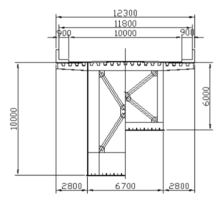
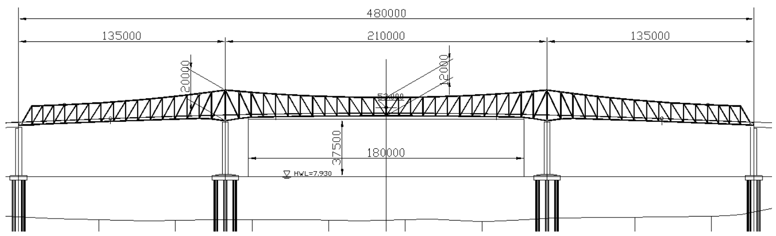
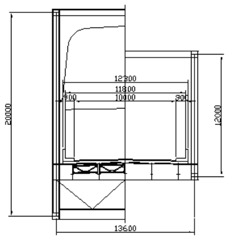
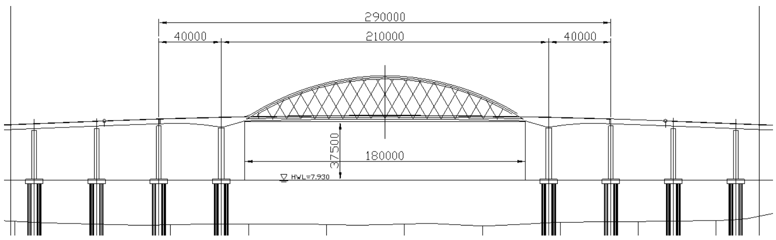
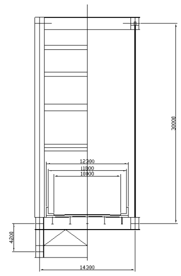
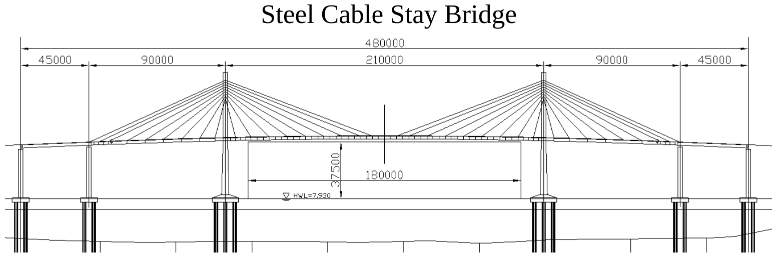
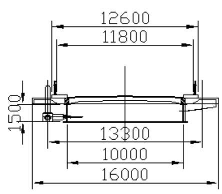
Sub-criteria for the evaluation of construction method are adopted as follows:

- Construction term
- Safety for the construction.

4) Maintenance

Aesthetic viewpoint

As results of the evaluation by AHP method, two cable stay bridges, i.e. Steel Cable Stay Bridge and PC Cable Stayed Bridge are developed for more detailed study. These two cable stay bridges are evaluated in detail, and as the consequence, PC Cable Stay Bridge is found most preferable at the construction site of the Project in Cambodia. The procedure for the evaluation of six bridges by AHP method is described in Appendix 5.5 and detail comparison of Steel Cable Stay Bridge and PC Cable Stay Bridge are shown in Appendix 5.5. Study of span arrangement for the Main Bridge is shown in Appendix 5.5.

	PROFILE	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 	

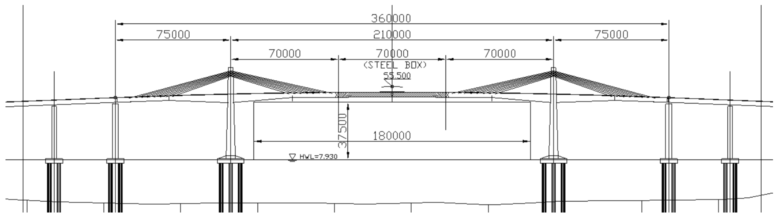
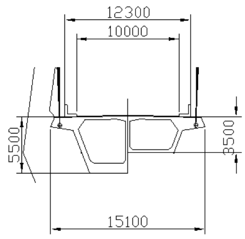
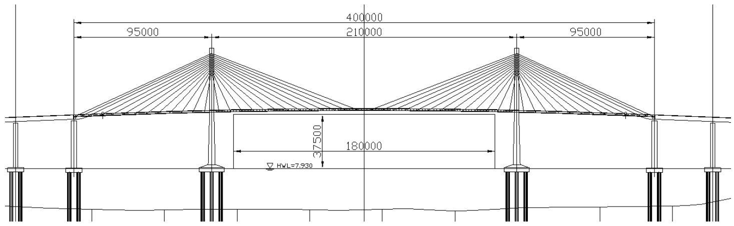
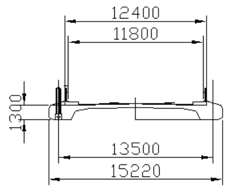
Type 5	Extra-Dosed PC Steel Composite Bridge 	
Type 6	P. C. Cable Stay Bridge 	

Figure 5.5.7 Alternative of Main Bridge (1)

Table 5.5.7 Comparison of Main Bridge Types

		Description
Type 1	Cost	Economical span length of this type is shorter than 150m.Construction cost is higher than Type 6. (Cost ratio for Type 6 is 1.35)
	Property of Structure	Girder height will be 7m high and bridge lengths will be 350m longer than other bridge types. Orthotropic deck shall be adopted.
	Construction	Side span will be erected by floating crane and center span shall be erected by lifting method. In case, floating crane over 1000 ton is not available, side span shall be erected by bent on the crawler crane on barge and construction yard for assembling the girder is required.
	Maintenance	Corrosion resistant steel or long life rust proof painting shall be adopted. In case of painting, repainting is necessary at 20 to 30 years interval.
	Aesthetics	Not so much impressive as a landmark, since it is an ordinary bridge shape.
Type 2	Cost	Economical span length of this type is shorter than 110m.Construction cost is higher than Type 6. (Cost ratio for Type 6 is 1.33)
	Property of Structure	Assembled by the small component.
	Construction	Same construction method of Type 1 could be applied. It is possible to erect the main span by cantilever method by using traveler crane.
	Maintenance	Same as Type 1 but maintenance of this type of bridge is most complex because of many members of the bridge.
	Aesthetics	It is possible to make the appearance attractive by the arrangement of members of the bridge. However, it seems to be an old fashion.
Type 3	Cost	Erection cost of this type is higher than Type4, Type5 and Type6. Construction cost is higher than Type 6. (Cost ratio for Type 6 is 1.27)
	Property of Structure	Main span cannot be assembled at the construction site.
	Construction	The crawler crane on the barge shall erect side span, and the center span will be erected by the lifting method. The assembling yard is required near the construction site.
	Maintenance	Same as Type 1
	Aesthetics	Better impression as a symbol and landmark of the highway compared to Type 1 and Type 2

		Description
Type 4	Cost	Steel girder is produced in other country. Construction cost is higher than Type6. (Cost ratio for Type 6 is 1.02)
	Property of Structure	Steel and concrete composite type cable stay bridge with two I-section girders. Tower and deck shall be concrete taking into account the cost like BIN Bridge in Vietnam. The wind tunnel test to check the stability against the wind force is necessary.
	Construction	Main span and side span will be constructed by the balanced cantilever method from the tower. The girder is lifted from the barge section by section.
	Maintenance	Same as Type 1 as to the maintenance of girder. However, the area for the painting is rather smaller than other alternatives. Routine inspections for cable system are required but the maintenance for the cable is hardly required
	Aesthetics	Generally speaking, the cable stay bridge is highly evaluated from the aesthetic point of view.
Type 5	Cost	Main bridge uses concrete and steel composite girder. Construction cost is higher than Type 6. (Cost ratio for Type 6 is 1.14)
	Property of Structure	Material of tower and 80% of girder are concrete and most of the basic materials are available in Cambodia. The girder height is about 3.0 m, so that the elevation of bridge surface will become higher, accordingly.
	Construction	Side span and center span are constructed by balanced cantilever method. Steel girder at the center of main span will be erected by lifting method from the barge. The construction yard for assembling the steel girder is required
	Maintenance	Maintenance for the steel girder is the same as Type 1. However, the area for the painting is considerably small. Routine inspection for the cable system is required, however actual maintenance for the cable is hardly required.
	Aesthetics	Low profile of tower makes the bridge less impressive, however this type will be highly marked as a symbol or landmark of the region.
Type 6	Cost	Construction cost is the most economical for main bridge. (1.00)
	Property of Structure	Every structure should be planned to use concrete and the major materials are available in Cambodia. Stability against the wind will be warranted, however wind tunnel test shall be implemented for confirmation of safety.
	Construction	Main span and side span will be constructed by the balanced cantilever method from the tower. Main girder will be constructed by cast in place concrete with the block length of 4.0m. The interval of cable will be 8m and erection of each block goes through the same procedure.
	Maintenance	Compared to other types of the bridge, maintenance is not much required, except for bearing, expansion joint and other drain system. Routine inspections for the cable system are required, however the actual maintenance for the cable is hardly required.
	Aesthetics	Generally speaking, the cable stay bridge is marked high in evaluation from the aesthetic viewpoint.

(2) Pier Arrangement for Local Ship Collision

The pier arrangement of the main bridge has been discussed through the Steering committee and officials of MPWT, and it was revealed that local ships often collide with piers in the Mekong River, especially during a high water season when the velocity of the river flow is swift. In addition, local ships tend to navigate near riverbank; therefore, it is desirable not to build obstacles in the area. The Mekong River Commission also recommends that “ the Mekong River shall be kept free from obstruction, measures, conduct and actions that might directly or indirectly impair navigability, interfere with this right or permanently make it more difficult” (Please refer to Appendix 5.5.)

Accordingly, the Study Team explored to minimize the number of piers in the River and eventually to minimize local ship collision accidents caused by the bridge. Three alternative types of the main bridge are compared for this purpose. These alternatives are:

1. 3-Span Continuous Steel Truss Bridge, main span 240 m.
2. 3-Span Through Arch Bridge, main span 210 m.
3. 3-Span Cable Stay Bridge, main span 320 m.

The Steel Truss Bridge and Through Arch Bridge are inferior to the Cable Stay Bridge in terms of both construction cost and maintenance cost as compared in Figure 5.5.6. Consequently, the Cable Stay Bridge as the main bridge is selected for further analysis.

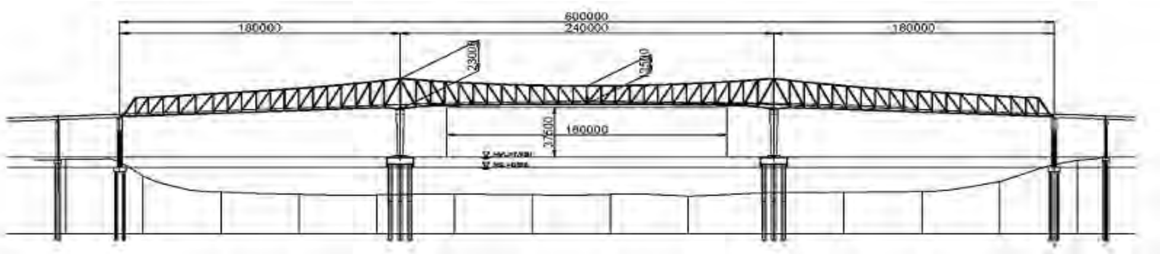
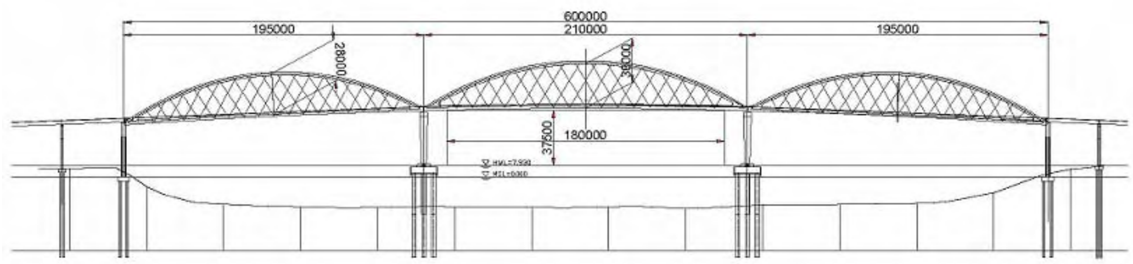
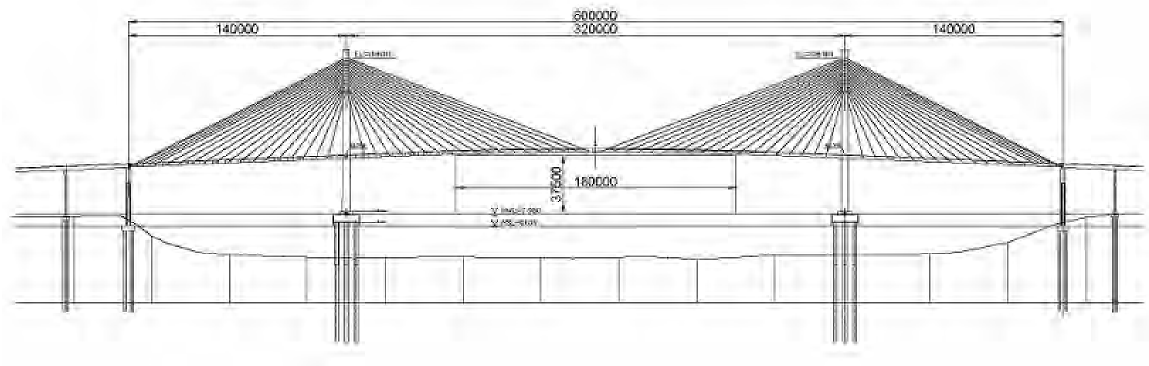
	PROFILE	DESCRIPTION
STEEL TRUSS		Cost for Main Bridge : Superstructure 38 million US$ Substructure 10 million US$ Total 48 million US$ Super Structure is assembled by small component and Side span shall be elected by the floating crane. It is possible to be erected the main span by cantilever method. Maintenance works for this type of bridge are complex. Major material for super- structure shall be imported.
THROUGHARCH		Cost for Main Bridge : Superstructure 44 million US$ Substructure 11 million US$ Total 55 million US$ Super structures are hardly assembled at the construction site. Large scale floating cranes are required for the erection of the superstructure. Major material for super-structure shall be imported.
CABLESTAY		Cost for Main Bridge : Superstructure 22 million US$ Substructure 10 million US$ Total 32 million US$ Main span and side span will be constructed by the balanced cantilever method from the tower. Major materials for structures are available in Cambodia.

Figure 5.5.8 Alternative of Main Bridge (2)

The Project in terms of the section can be summarized as follows: the total length of the Project is 5,420 m, including the 600 m-long main bridge, the approach bridge with its length of 960 m and the approach road of 800 m in the west side, and the approach bridge of 660 m and approach road of 2,400 m in the east side of Neak Loeung.

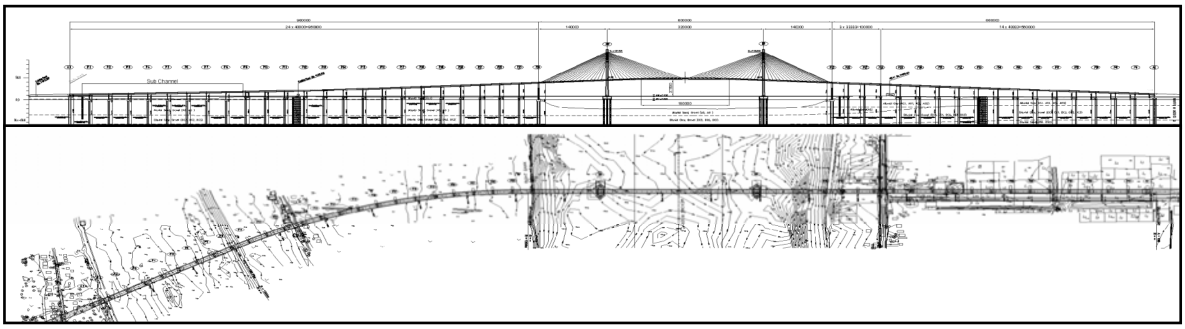


Figure 5.5.9 General View of the Project Bridge

5.5.6 Selection of Approach Bridge Type

(1) Study of the Optimal Span Length for Approach Bridge.

The construction cost is one of the most important evaluation factors for the selection of bridge type for the approach bridge. The construction cost of the bridge is estimated by the span length with the cost of super structure being combined with the cost of the substructure as shown in Figure 5.5.10. Several types of bridges which commonly constructed in Japan are nominated as shown in Table 5.5.8.

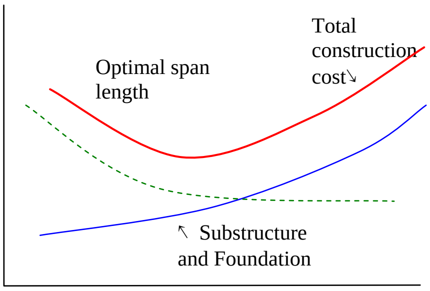


Figure 5.5.10 Cost of the Bridge

(2) Optimal Span Length for the Approach Bridge

The following formula is applied to determining the optimal span length of the approach bridge:

$$L = (1.0 \sim 1.5) \times (H + 1/3 \times D)$$

Where;

L: Optimal Span length (m)
H: Height of Pier (m)
D: Depth of Foundation (m)

Source: Manual for Bridge Design, Japan Highway Public Corporation July 1998.

Average height of pier is 20 m and average length of the pile foundation is 50 m, therefore the optimal span length for the approach bridge ranges from 35 m to 55 m.

Table 5.5.8 Optimum Bridge Span Length of Each Type of Bridge

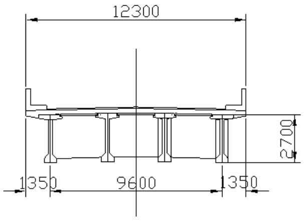
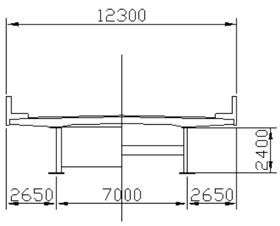
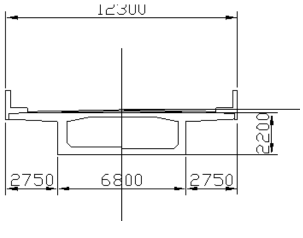
Type of Bridge			Span Length (m) 10 20 30 40 50 60 70 80 90	Curved Bridge	Ratio of Girder height and span length
Steel Bridge	Simple I Girder			×	1/17
	Continuous I Girder			×	1/16
	Simple Box			○	1/22
	Continuous Box			○	1/23
	Simple Truss			×	1/9
	Continuous Truss			×	1/10
	Arch			×	1/6.5
Concrete Bridge	Pre Tension Girder			×	1/15
	Hollow Slab	RC		○	1/20
		PC		○	1/20
	PRC I Girder			○	1/17
	PC Composite			×	1/15
	PC Continuous Compo.			×	1/15
	PC Simple Box			○	1/20
	PC Continuous Box (Staging Method)			○	1/18
	PC Continuous Box (Cantilever method)			○	1/18
	PC Rahmen with diagonal Strut			×	1/32
	PRC Portal Rahmen			○	1/30
	RC Arch			○	1/2

Source: Design Manual, Japan Highway Public Corporation July 1998

Note: Ratio of girder height and span length of the arch indicates that of arch rise and span length, "○" in Curved Bridge means that the girder can adjust itself along the curve, and "×" means it cannot.

Taking into account the optimum span length estimated by the aforementioned formula, three bridge types that could be adopted to the approach bridge are selected as shown in Table 5.5.9.

Table 5.5.9 Bridge Types Nominated for the Approach Bridge

	Cross Section	Description	
Type 1 PC Continuous Composite I girder		Cost	Construction cost is the lowest among 3alternatives.
		Property of Structure	Pre-tensioned concrete boards are utilized for the form of deck. Durability of deck is improved and the wooden forms are unnecessary. Post-tensioned girders could be manufactured in parallel with the construction of substructures, and keep them at the stock yard. This type is adopted for approach of Kizuna bridge.
		Construction	Erection girders utilized to erect girders and the deck concrete is cast on the PC board, which is set between the girders. Construction of deck is easier than that of Type 2 shown in this table, but cross beam and the connection girder become complicated.
		Smoothness	Five span continuous connection girders could reduce expansion joints which are cause of the shock to the car.
		Maintenance	Maintenance, except for bearings and expansion joints, is hardly required.
		Aesthetics	Details at the connection of the girder are not smart.
Type 2 Steel Continuous I Girder		Cost	Steel girder shall be produced in other country. Construction cost is higher than Type 1.
		Property of Structure	Post-tensioned concrete P.C. decks are constructed by using movable form.
		Construction	Main girder could be erected by erection girder and PC deck slab are constructed. Construction method is rather simple compared to Type 1
		Smoothness	Continuous girder minimizes the number of joints and attains a smooth vehicle run.
		Maintenance	Long life with 20 to 30years of lust proof paint is necessary. The structure is simple and the maintenance is easier than the ordinary steel structure.
		Aesthetics	Simple structure with coloring and the large overhang of slab make good impression.
Type 3 PC Continuous Box Girder		Cost	Construction cost is obviously high compared to the girder bridge.
		Property of Structure	Slab and girder are united and the road surface is smooth without expansion joints by continuous girder.
		Construction	Constructed by the movable support or incremental launching method. Large-scale construction equipment is necessary. Construction term is longer than other construction methods
		Smoothness	Continuous girder minimizes the number of joints and attains a smooth vehicle run.
		Maintenance	Maintenance work, except for pavement and expansion joint, is not required.
		Aesthetics	Simple appearance and long overhang of the deck make a smart impression

(3) Study of the Optimum Bridge Span Length for Approach Bridge

The construction cost is estimated by referring to the costs of existing projects in Cambodia and other Asian countries. Estimated cost results of each bridge type are shown in Figures 5.5.11 to 5.5.14.

Figure 5.5.11 shows the construction cost of Steel Continuous I Girder. It appears that the most economical span length is 40 m. The construction cost of PC continuous Composite I Girder is shown in Figure 5.5.12. According to this figure, the most economical span length is also 40 m. The construction cost of PC Continuous Box Girder is shown in Figure 5.5.13. Total cost of this type of bridge is rather high compared to other two types of bridges.

Figure 5.5.14 shows the total construction costs of three alternative bridges. PC continuous composite I girder is preferable among three types of bridges in terms of cost, maintenance and construction experiences in Cambodia. Therefore, it is recommended that 40 m span length of PC continuous I girder should be adopted for the approach bridge.

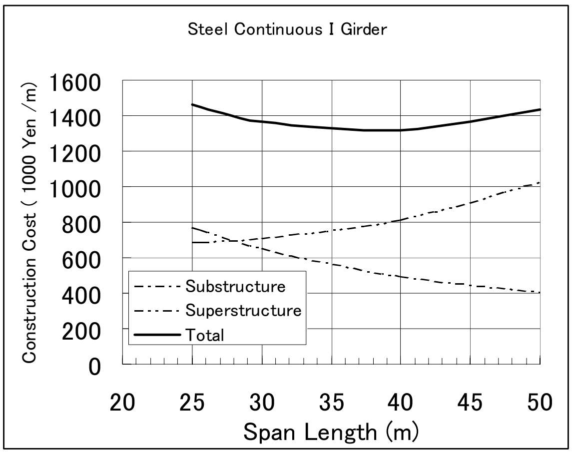


Figure 5.5.11
Steel Continuous I Girder

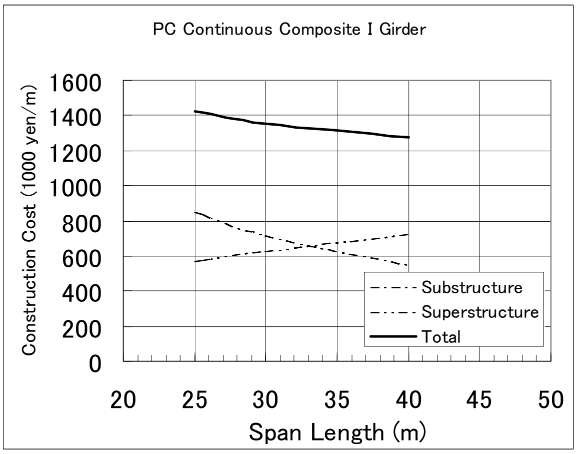


Figure 5.5.12
PC Continuous Composite I Girder

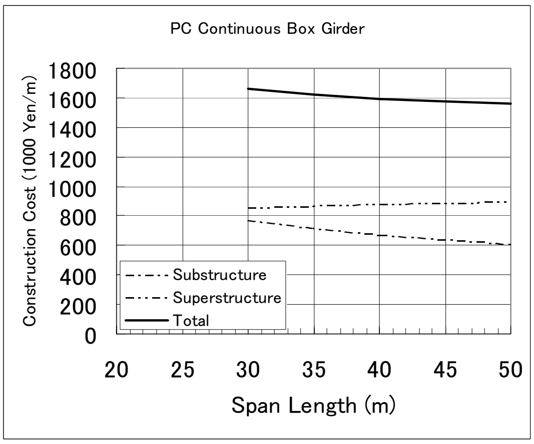


Figure 5.5.13
PC Continuous Box Girder

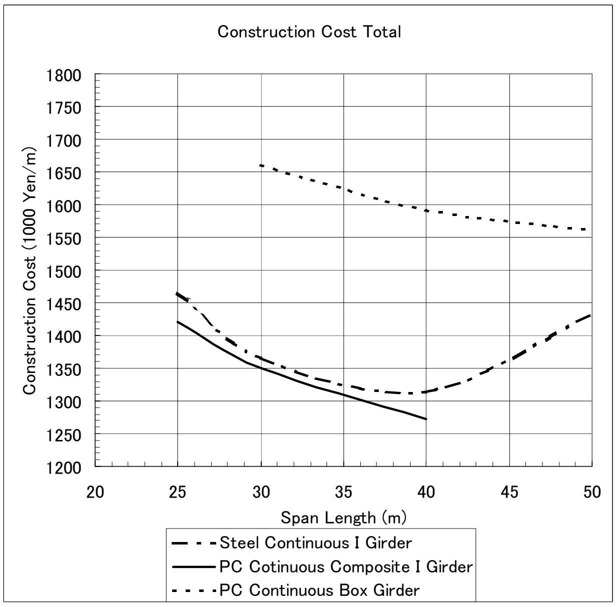


Figure 5.5.14
Summary of Total Construction Cost

5.6 Preliminary Bridge Design

5.6.1 Introduction

Preliminary bridge designs have been developed following concept of the structures selected by the study in Section 5.5 5.

1. Prestressed concrete three-span cable stay bridge, 320 m main span and two side spans, each of 140 m, total bridge length 600 m.
2. Prestressed concrete continuous composite I–Girder with 40 m span length.
3. Pylons with vertical columns with cross-beams.
4. Hexagonal Pile Cap for Pylons in the river
5. Cast in Place Concrete Pile with Steel Casing for foundations in the Mekong River
6. Cast in Place Concrete Pile for foundations on land.

5.6.2 Main Bridge

(1) Bridge Layout

Cable Stay Bridge with a maximum spans length of either 210 m or 320 m are studied in the preliminary chapter and they indicate a suitable cost competitiveness at this bridge location. The single lane navigation width and the elimination of side span piers in the river minimize the risk of local ship collision. Thus, Three-Span continuous span arrangement, which is comprised of a main span of 320 m and two side spans of 140 m each, total bridge length of 600 m, has been adopted for preliminary design for this study. The two pylons are located almost even distance from the center of the river and provide a good shipping approach to the opening of the navigation channel. The profile of the main bridge is shown in Figure 5.6.1

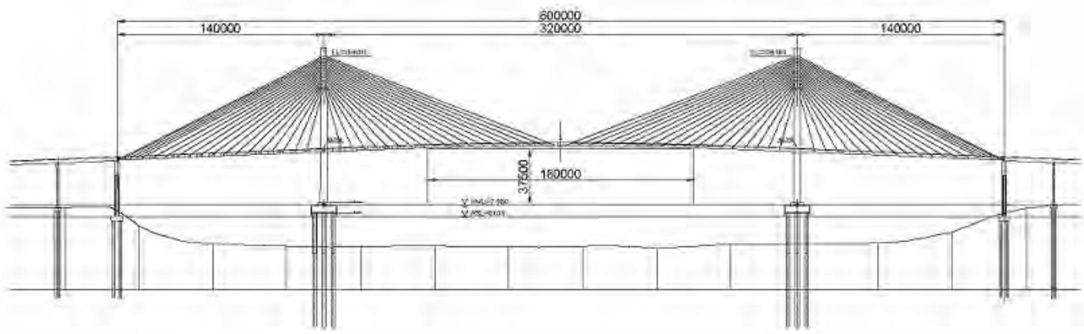


Figure 5.6.1 Layout of the Main Bridge

(2) Bridge Deck

The prestressed concrete deck and the steel deck are studied in the previous section. Weight of the concrete deck is heavier than the steel deck. However the cost of the concrete deck should be more economical and easy to maintenance. In case of the concrete deck, the concrete box girder type and two main girders type could be adopted to the bridge deck for this type of bridge. The two-main-girders type is adopted as a bridge deck in this project because of its simplicity for the construction, good aerodynamic performance and appearance. The two-main-girder is connected by the reinforce concrete deck and the cross beam. The cross section of the two-main-girder is shown in Figure 5.6.2. The interval of the cable should be 8.0 m and the length of one construction segment of the bridge deck is 4.0 m. The bridge deck will be constructed by cantilever method from each pylon toward center span and side span in balanced operation. The bridge deck could be constructed by cast in place concrete or pre-cast segments, and the cast in place concrete method will be selected to utilize simple construction equipment. Deck and the cross beams of pylon are connected by the rubber bearing and the deck is supported in horizontal direction by lateral bearings at each sub-structure of the main bridge.

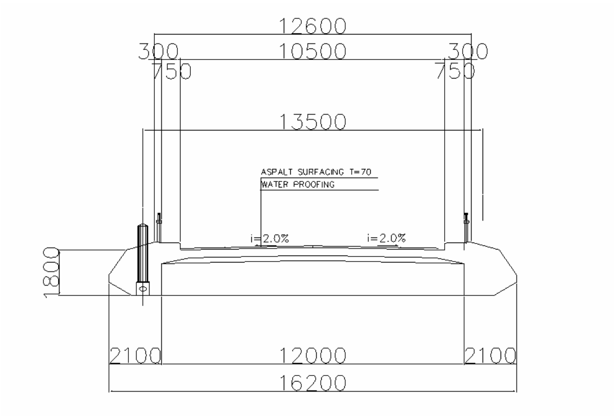


Figure 5.6.2 Typical Cross Section of Cable Stay Bridge

(3) Pylons

The concrete vertical parallel pylon with the cross beam (H shaped pylon) is adopted as the pylons for the main bridge, since it is considered that this type of pylon would achieve a preferable visual impact from drivers and cost efficiency. Arrangement of stay cables is semi-fan pattern which is suited for the construction of cable anchors in concrete pylons. Height of the pylons is 105 m from the surface of the pile cap and about 68 m from the road surface to keep the 37.5 m vertical navigation clearance. The tall concrete pylon will be constructed by sliding form or slip form method and concrete shall be cast continuously during the election of the tower. The A-shaped pylon also has a high resistance to lateral loads. However, the benefit will be achieved for the bridge with a main span length over 400 m. A general view of the pylon is shown in Figure 5.6.3.

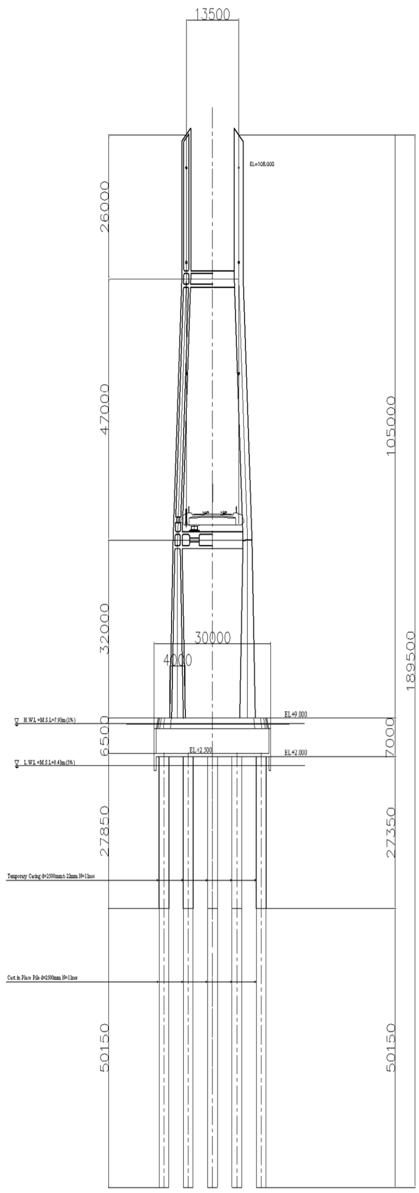


Figure 5.6.3 General View of the Pylon

(4) Stay Cables

There are two types of the stay cable, they are Multi Strand (MS type) and Parallel Wired Strand (PWS) applicable to the main bridge. Multi Strand Cable consists of bundle of parallel mono strands coated by grease for protection from friction and sheathed in a high density polyethylene (HDPE) tube. In addition, bundle of the multi strand cable are encased in the high density polyethylene duct and the compound for corrosion prevention is filled in the duct. Equipment for installing the stay cable at the construction site is rather simple.

The Parallel Wire Strand is fabricated in the factory. Bundle of galvanized wire is rolled up by filament tape and sheathed in the HDPE tube. Unit of the stay cable is heavier than MS type cable and equipment to install the cables at construction site will be heavier than the equipment for MS type. The MS type of stay cable is preferable to adopt the prestressed concrete cable stay bridge which is constructed at the remote area from the factory.

(5) Foundations

Based on the geological and hydrological information of the river, cast in place concrete piles, partly steel cased, are considered appropriate for foundations of main bridge pylons, as studied in Section 5.5.4. The large free length of piles in the deep water in the river and allowance of local scoring need to provide enough strength of pile foundation system. 11 piles with 2.5 m in diameter are capable to both supporting the bridge and withstanding the ship collision. Hexagonal pile cap is designed to minimize the pressure from the river flow and the collision force from the vessel. The pile arrangement under the pile cap is shown in Figure 5.6.4

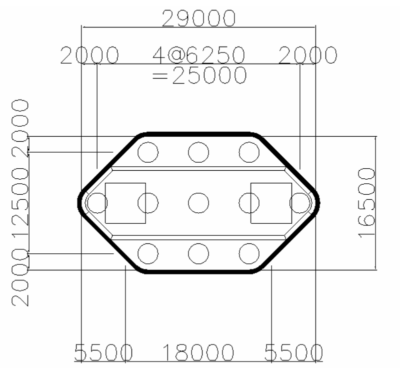


Figure 5.6.4 Arrangement of Pile for Multi Column Foundation

5.6.3 Approach Bridges

(1) Super Structure

Precast Prestressed concrete I-girder with 40 m span length is adopted to the superstructure of approach bridge as studied in section 5.5.6. The approach bridge are located mainly on land, except for the shallow water section of the Mekong River tributary. The proposed bridge type is technically less complicated and cheaper to construct compared to other bridge types. The Precast beams are fabricated and stocked at construction yards on both sides of the approach roads. The girder will be erected on the pier by mobile crane from the ground and transport to the pier location by election girders. The deck slab will be made continuous over five spans to minimize the number of expansion joints which minimize the shock to the vehicle and save the maintenance cost.

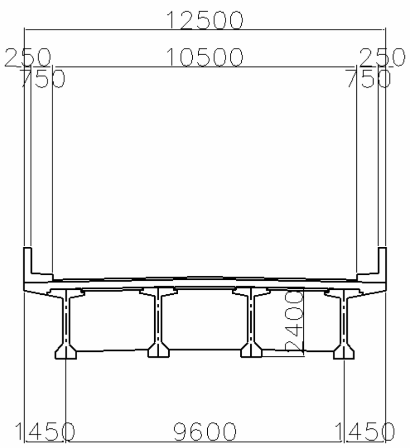


Figure 5.6.5 Typical Cross Section of Approach Bridge

(2) Substructure and Foundation

Based on the information from the geotechnical survey, it is considered possible to support the substructure of approach bridge by 1.0 m diameter cast in place concrete piles and the length of the pile will be about 55.0 m. The presence of a soft soil layer on surface at both sides of the river bank will require a careful investigation of the negative friction, the effect of down drag for pile foundations caused by the ground subsidence.

5.6.4 Miscellaneous Facilities

(1) Facilities for the Safety for Traffic on Road, River and Air

The facilities for the safety measures for traffic shall be provided through the project. The major facilities involved in the project are:

a. Lighting on the bridge and approach roads

To illuminate carriageway on road and bridge, it is inevitable to provide high and low pressure sodium lamp on conventional galvanized steel pole.

b. Navigation lights for vessels for inland water traffic including the fog signal station light.

Navigation lights to delineate the navigation channel, shall be provided as follows:

- the center of the main span to show the height of navigation channel.
- the piers in the river to illuminate the piers.

Fog signal device which provides warning to the vessels approaching the bridge in foggy conditions is recommended to be installed on the bridge. The device should provide a 2-km range fog audio warning signal with light attached to the device, flashing in synchronization with the audio signal.

c. Aircraft warning light

A height of the tower of the cable stay bridge is over 100 m, and aircraft warning light shall be installed on top of the tower to provide warning to aircrafts flying at low level.

(2) Electricity Supply

Electric power is supplied to the Neak Loeung area by the private power supplier Nov Rotha. However it is not sufficient to supply electric power to the Bridge. There is a plan to construct a power line from Svey Rieng to Neak Loeung by 2016. Before the completion of the power supply line, electric power for the bridge shall be supplied through self power generation. Additionally, back up power supply source such as solar battery shall be prepared especially for the navigation light in case of power failure.

(3) Deck Drainage

A drainage system shall have a sufficient capacity to collect surface water on the bridge decks efficiently. The longitudinal drainage pipe will be installed at the back of the kerb with collection hole at each side of the bridge which remove the storm water from the bridge deck.

(4) Addition to the Bridge

Lifelines such as the water supply pipe, electricity cable and optical fiber cable are usually placed to the deck of the bridge to cross the river. However, the future plan for such facilities at Neak Loeung is not yet structured. Therefore, in the next stage of the study, it is necessary to examine the future plan, if structured, in order to design the space for lifelines.

5.6.5 Protection Work for Substructure

(1) Protection from River Flow

Bridge facilities, including the pier and abutment, should be carefully designed not to obstruct the flood flow of the Mekong River, and to minimize the structural defect caused by scouring of piers and erosion of abutments.

In consideration of river facilities design, the following aspects should be examined.

1) Erosion

There is no significant meander on the main course of the Mekong River in/around Neak Loueng. Therefore, the direction of the river flow in this area is parallel to the riverbanks and there are only some parts of the riverbank eroded by the flood. Based on the hydrological survey of this Study, there is some possibility that the erosion of riverbank may occur. Along the optimum route of the project road and bridge, the riverbank along the left side of the river tends to be eroded. No significant erosion is observed in the right bank along the optimum route.

The installation of the embankment, groin and revetment are generally considered as the measures for the erosion.

2) Scouring

According to the result of the geological survey in the Study, the depth of the riverbed along the proposed route is approximate 20 m below MSL. Hard sand stratums are at a depth of around 50 m below MSL. Between the river bed and hard sand stratum, there is an alluvium, of which thickness varies from 10 to 30 m and scouring of the riverbed will occur in the alluvium layer.

In general, the scoring depth of the riverbed at the downstream of the bridge foundation is the major factor of the bridge design. Several empirical formulas are developed to determine the scoring depth.

3) Flood Plain

Bridge structures, including the piers, abutments and embankments of the approach road, are influenced by condition of the flood and are affected especially by the flood flow. The proposed route, in general, is located in the flood plain of the Mekong River and that in the left bank area passes by the Stueng Slout River as well.

(2) Protection from Scouring

The riverbed will be found at approximately -20 meters below MSL along the bridge route. There is an alluvium between riverbed and diluvial formation and the thickness of the alluvium is about 10 to 30 m. Scoring of the riverbed will occur in the alluvium and the safety of foundations of the bridge is affected by the degree of scoring.

The Larcy's empirical formula is applied for the estimation of scouring depth of the alluvium. This formula is considered appropriate for the sandy material in the riverbed and is applied to the analysis of scoring in the F/S of Kizuna Bridge[1].

1 The feasibility Study on Construction of a Bridge on Mekong River in the Kingdom of Cambodia, Vol.2, Main Report, July 1996.

Silt factor (*f*) applied to the Larcy's formula is presumed as 1.0 based on the average grain size of the riverbed material (D_{50}). The maximum scoured depth (D_s) is calculated by multiplying a coefficient (f_0) 2.0.

$$y_r = 0.47 \cdot (Q/f)^{1/3} = 0.47(34{,}000/1.0)^{1/3} = 0.47 \times 32.396 = 15.226$$

$$D_s = f_0 \cdot y_r = 2.0 \times 15.226 = 30.451 \approx 30$$

According to the above formula, the maximum scoring depth is estimated at 30 from HWL, it means 2 to3 meters from the river bed. In case of KIZUNA Bridge constructed in 2002, the maximum scoring depth was estimated 15 m by the same formula. Therefore, rip-rap was applied as protection works. According to the scoring survey[2] at Kizuna Bridge, the scoring depth was only less than 3 m and no serious problem has occurred at all piers. The effectiveness of the rip-rap method was confirmed at Kizuna Bridge. Therefore, rip-rap apron is recommended as the protection of the Second Mekong Bridge. In addition, the following formula is derived from the previous study[3].

$$Vc=1.2x(\sqrt{2.g}) \cdot (\sqrt{(S-1)} \cdot D)$$

where,

Vc: velocity of river flow (m/s)
g=9.81(m/s2)
S: Rock density=2.6
D: Rip rap size (m)

The extent of rip-rap apron should cover a distance equal to 1.5 times the width of multi-column foundation from each edge. The average stone size is determined depend on the results of the hydraulic analysis taking into account the local flow velocity of the river. Thickness of rip-rap should be twice the average of stone size. If the Vc is 3.0 m/s(1.5 times of the average flow velocity=2.0 m/sec), the diameter of rip-rap is estimated as 20 cm.

[2] The project for Construction of a Bridge over Mekong River, Construction report, Ministry of Public Works & Transport. August 2001

[3] Ho Chi Minh City to Phnom Penh Highway Improvement Project, Hydrology and Hydraulic Study Appendix-5, page 1/3

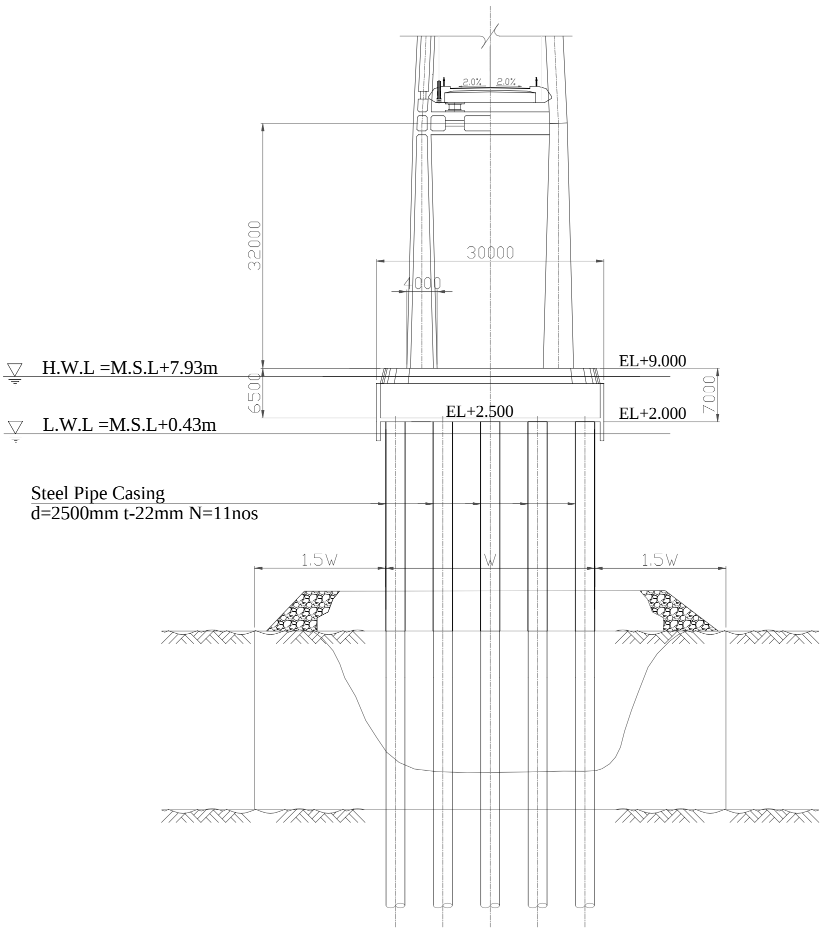


Figure 5.6.6 Scoring Protection at Piers

(3) Protection of Foundations in the River

There are some risks that ships navigate through the river will collide with a pier in the river. It is viable to design the foundation of pylons with additional piles and strengthened pile caps to withstand the impact from ships. The shape of the pile cap has to be designed to minimize the effect of the ship impact, particularly in the case of direction with perpendicular or near perpendicular to the centerline of the bridge. Protection of the pile cap by fender may need to be considered in the final design based on the total cost compared between foundation, with fender and without fender. Fender would provide protection against impact by local ships, particularly in the case of collision with small local ships, fender would minimize the damage and protect small vessels. An example of the fender as a protection for foundations in the river is shown in Appendix 5.5.