No. 1

Ministry of Resources and Development
The Republic of Palau

BASIC DESIGN STUDY REPORT ON THE PROJECT FOR CONSTRUCTION OF A NEW KOROR-BABELDAOB BRIDGE IN THE REPUBLIC OF PALAU

DECEMBER 1998

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PREFACE

In response to a request from the Government of the Republic of Palau, the Government of Japan decided to conduct a basic design study on the project for construction of a new Koror–Babeldaob bridge in the Republic of Palau and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Palau the study team, two times from March 18 to April 16, 1998 and from July 5 to July 29, 1998.

The team held discussions with the officials concerned of the Government of Palau, and conducted a field study at the study area. After the team returned to Japan, further studies were made. Then, a mission was sent to Palau in order to discuss a draft design, and as this result, the present report was finalized.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Palau for their close cooperation extended to the teams.

December 1998

Kimio Fujita
President
Japan International
Cooperation Agency

December 1998

LETTER OF TRANSMITTAL

We are pleased to submit to you the basic design study report on the project for construction of a new Koror–Babeldaob bridge in the Republic of Palau.

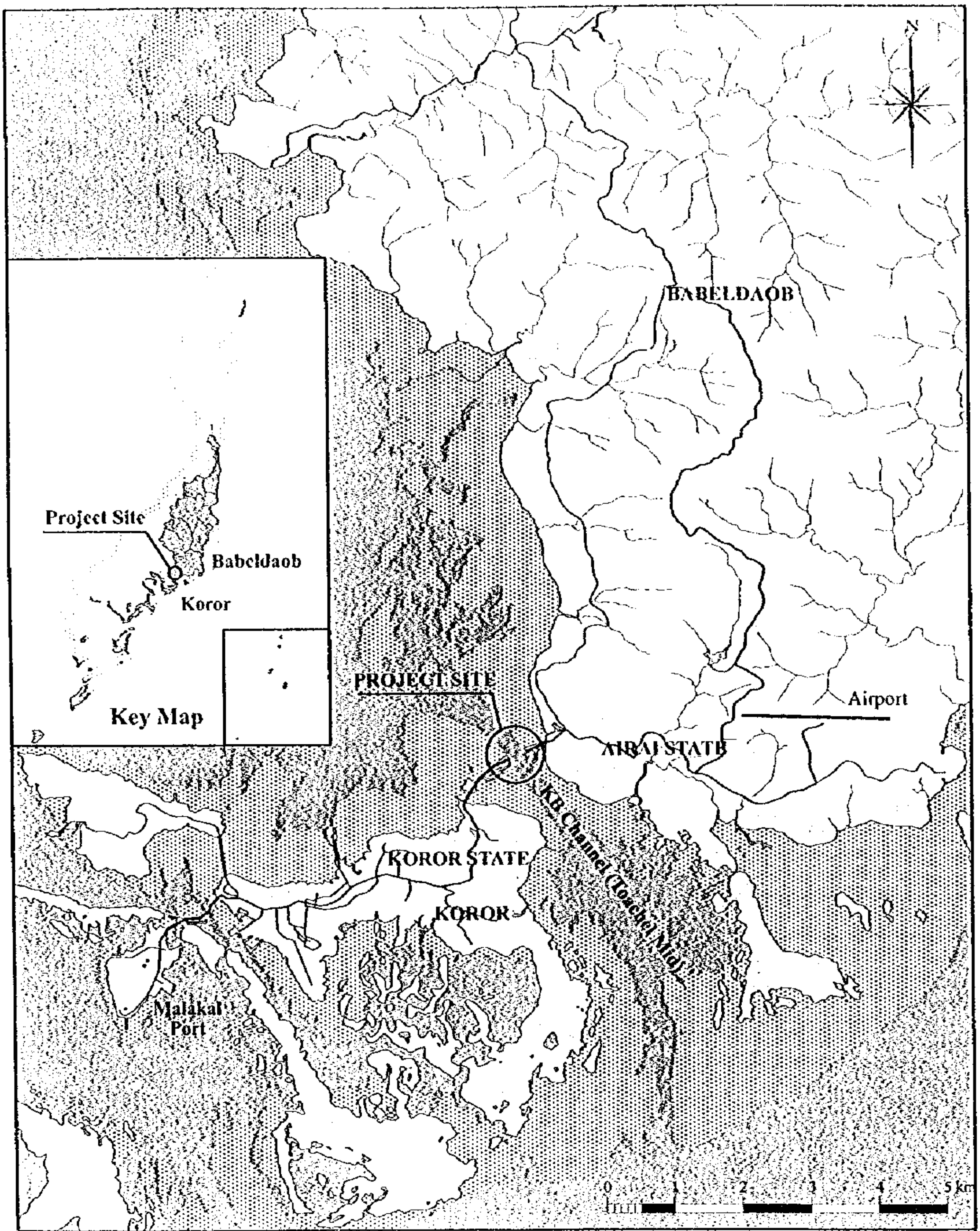
This study was conducted by Nippon Koei Co., Ltd. in association with Oriental Consultants Co., Ltd., under a contract to JICA, during the period from 2 March 1998 to 3 December 1998. In conducting the study, we have examined the feasibility and rationale of the project with due consideration to the present situation of Palau and formulated the most appropriate basic design for the project under Japan's grant aid scheme.

Finally, we hope that this report will contribute to further promotion of the project.

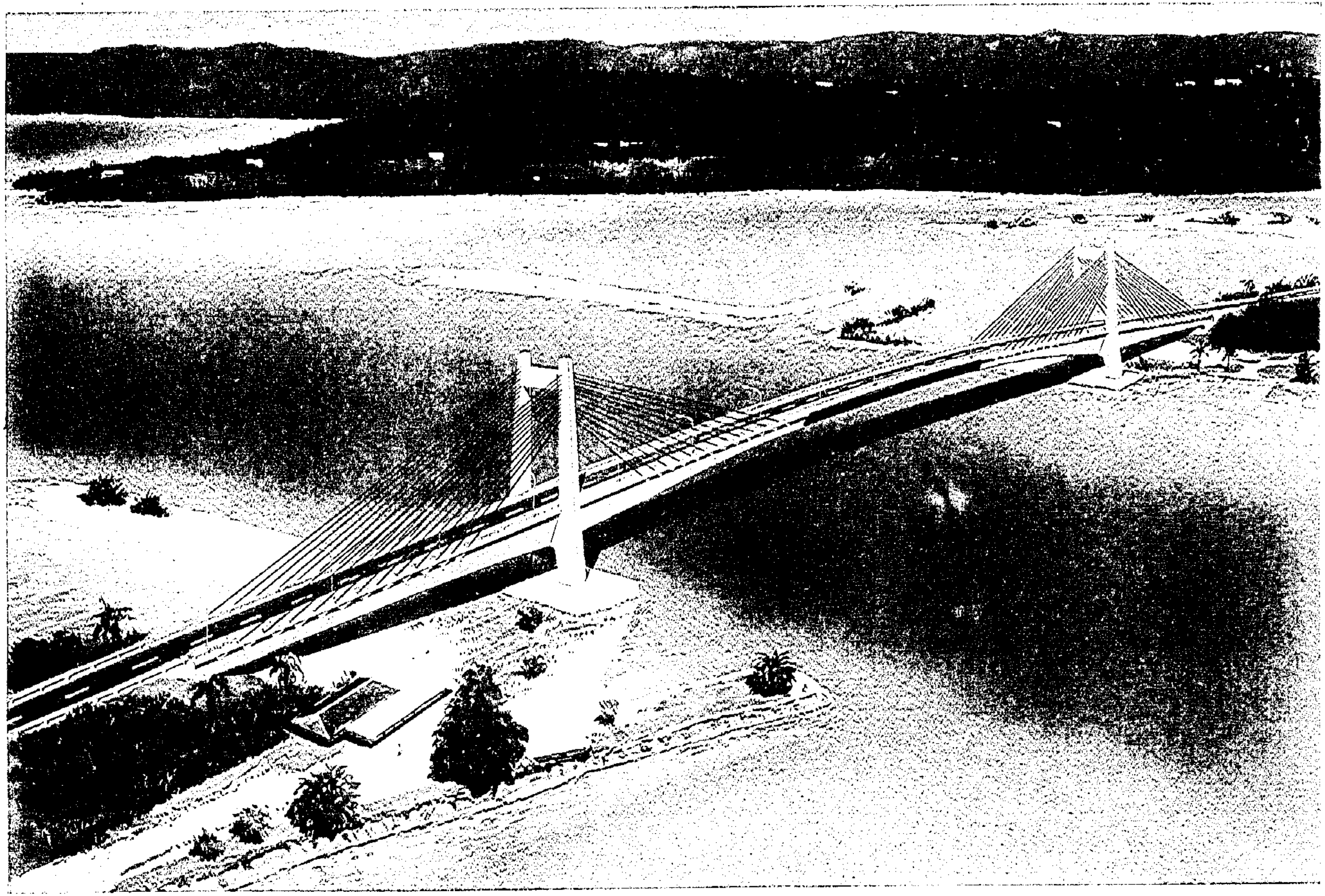
Very truly yours,

H. Oshima

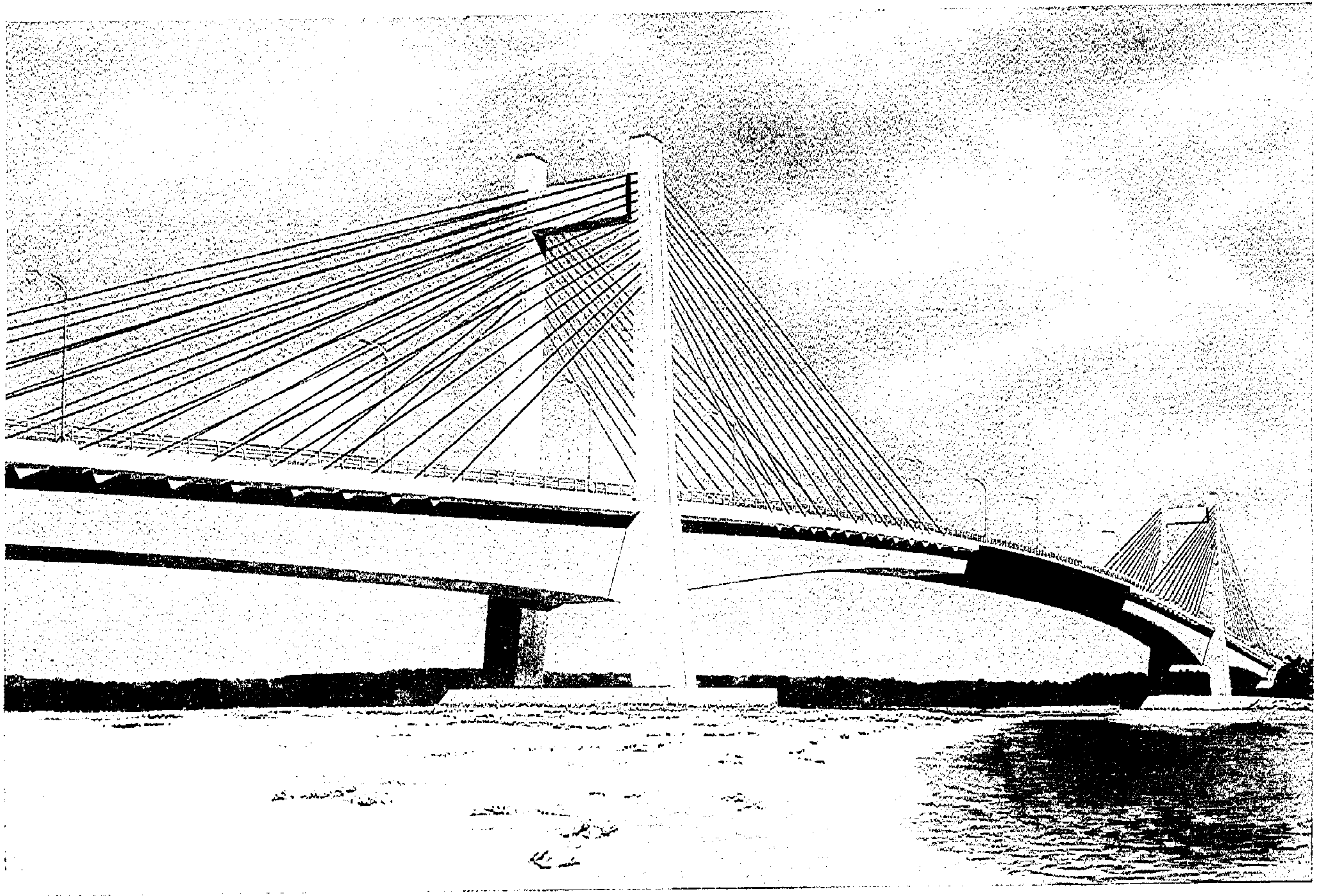
Hisashi Oshima
Project Manager
Basic design study team on
the project for construction of Koror – Babeldaob bridge in the Republic of Palau
Nippon Koei Co., Ltd. in association with Oriental Consultants Co., Ltd.



Location Map



Perspective (1)



Perspective (2)

Abbreviations

AASHTO	:	American Association of State Highway and Transportation Officials
Alt	:	Alternative
EL	:	Elevation above sea level
E/N	:	Exchange of Notes
EQPB	:	Environmental Quality Protection Board
ICTV	:	Island Cable Television Incorporation
GOJ	:	Government of Japan
GOP	:	Government of Palau
JICA	:	Japan International Cooperation Agency
KB Bridge	:	Koror-Babeldaob Bridge
kN	:	Kilo- Newton
Max.	:	Maximum
Min.	:	Minimum
MOS	:	Ministry of States
MPa	:	Mega Pascal
MRD	:	Ministry of Resources and Development
N	:	Newton
N/A	:	Not Applicable
OPS	:	Office of Planning and Statistics
P.C.	:	Pre-stressed Concrete
PNCC	:	Palau National Communication Corporation
PNC	:	Palau National Congress (Fifth Olbiil Era Kelulau)
PUC	:	Palau Public Utility Corporation
RC	:	Reinforced Concrete
ROP	:	Republic of Palau
ROW	:	Right of way
t	:	Thickness
US	:	United States of America

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CHAPTER 1 BACKGROUND OF THE PROJECT

The Republic of Palau (ROP), an archipelago country at west corner of the Western Caroline Islands, stretches from about 2 to 8 degrees North latitude and 131 to 135 degrees East longitude with a total land area of 488 square km. The country cluster consists of 343 islands strewn along a line which begins with Kayangel in the north-east and ends with Angaur, 200km south-west and only nine islands are inhabited. The largest island among these is Babeldaob with a land area of 397 square km amounting to about 80 % of the total. Babeldaob is subdivided into ten states, and in Airai State on the southern tip of Babeldaob island, Palau International airport is located. From the airport a road leads Koror, the capital city of Palau, where political and economical center of Palau is located on the island of Koror adjacent to Babeldaob. The State of Koror consists Koror, Malakal and Arakabesan islands linking by roads. In 1995 census, Palau's population was 17,225 which was a 13.9 % increase compared with 15,122 in 1990. By state population, Koror which is highly populated is weighted 71% of the total population.

The only means of land transportation available in Palau is with vehicles. In 1997, the numbers of registered vehicles were about 6,500 and over 95% of the total are registered in the States of Airai and Koror. Overall, the total length of the road is estimated at 300 km and 32.8 km among these belongs to paved road in and around Koror State. The only commercial port available to handle international shipping in Palau is Malakal Harbor. The total cargo handled was about 100,000 tons in 1996 (96,000 tons imported & 7,000 tons exported) but the cargo handling equipment, container handling and storage space and wharves capacity are inadequate. The international airport with over 73,000 visitors per year located in Airai State faces inadequate runway capacity and navigational aids and deteriorated terminal building. The other major infrastructures in Babeldaob are power plant, dam and purification plant from which power and water are transmitted to Koror State.

Koror-Babeldaob Bridge (the KB Bridge), built in April 1977, connected Koror Island, the population, civic, administrative and commercial center of ROP with Babeldaob Island, the largest land mass where most of the natural resources of the country are found, as well as the locations of important facilities. On September 26,1996, the KB Bridge which is the most important structure in ROP suddenly collapsed and not only was the bridge destroyed but also the main utility lines which transmit water supplies, electricity, telecommunication lines and cable television from their sources in Babeldaob to Koror were cut. To date a temporary floating bridge has been installed for crossing KB channel but socio-economic activities in Palau are still suffering from various adverse effects such as increase of maintenance cost of the floating bridge, transportation cost and time, traffic accidents, and retrogression of Babeldaob development.

Under this situation, the Government of Palau (GOP) made a request for grant aid for the Project for Construction of A New Koror- Babeldaob Bridge (the Project) on December 1996 to the Government of Japan with the following project components:

-Design/Construction of New KB Bridge

-Relocation of Utilities of power line, water supply, telephone line and TV cable

-Demolition of Failed Bridge

-Reef Road Feasibility Study

CHAPTER 2 CONTENTS OF THE PROJECT

2.1 Objectives of the Project

Under Section 231 (a) of the Compact of Free Association with the United States, there is a requirement for an official national development plan to be promulgated by the Government of Palau and concurred with by the Government of the United States prior to the effective date of Compact implementation. An Economic Development Plan 1995-1999 was, therefore, released in June 1994 for the implementation of the Compact on 1 October 1994.

The Plan was designed to move towards more balanced economic growth throughout the country by creating an infrastructure foundation upon which all States can build sustainable economies. In the Plan it was defined that the expansion of the Republic's infrastructure will have the goal of ensuring such infrastructure as: healthy and safe drinking water and sanitation; reliable electrical communication systems; and appropriate transportation and government facilities. These infrastructure facilities are necessary for the health and well being of the Palauan people and are essential in order to create a base for private sector development which will lead to economic opportunities and benefits for the Palauan people.

Koror-Babeldaob Bridge (the KB Bridge) built in April 1977 connected Koror Island with Babeldaob Island, the largest land mass (90 % of the total land area) where most of the land based natural resources of the country are found, as well as the locations of important facilities. On September 26 1996, at 5:45 p.m., the KB bridge which is the most important structure in ROP suddenly collapsed, destroying not only the bridge but also the main utility lines which bring water supplies, electricity, telecommunication lines and cable television from their sources in Babeldaob to Koror. The temporary floating bridge has been constructed to date but socio-economic activities in Palau are still suffering various adverse effects.

The objectives of the Project are to replace the failed KB Bridge with a new, safe and permanent bridge and to provide stable transportation system.

2.2 Basic Concept of the Project

2.2.1 Basic Conditions To Formulate the Scheme

(1) Basic Conditions

The Project to be formulated in the Study covers only design and construction of a new KB bridge and excludes demolition of the failed bridge, relocation of utility lines, and reef road feasibility study.

The basic conditions applied in the Study to formulate the Project Scheme are as follows:

- Magnitude and capacity of the new bridge shall be more or less the same as the failed KB bridge, but the new bridge shall cope with various natural conditions at the bridge site.
- Reutilization of the existing piles is not considered in the Study since the actual concrete strength is likely less than the requirements and reliability and soundness of the existing piles are inferior to originally expected.
- For relocation of the utilities, the room and weight of these lines are considered in the Study but the relocation and reinstallation work shall be undertaken by the Government of Palau.
- The existing access roads presently available shall be utilized as much as possible.
- The design life of the new bridge shall be 50 years.

(2) Applicable Standards

The design standards to be mainly applied in the Study are as follows:

- Geometric Standard : A Policy on Geometric Design of Highways and Streets, 1994 by AASHTO
- Bridge Design Standard : Specifications for Highway Bridges published by Japan Road Association in December, 1996

In Palau, AASHTO Specifications are generally being applied to roads and bridges design. AASHTO Geometric Standard is, therefore, applied to the road way design in the Study.

AASHTO Standard Specifications for Highway Bridges is only applicable to ordinary highway bridges with span length less than 500 ft(152m) and is not applicable to unusual types as stipulated in the Specification. However, the Bridge Design Specifications in Japan provide wider applicability of bridge types and span length. Hence, the Japanese Bridge Design Specifications are applied mainly to the bridge design method in the Study except for design conditions governed by the local conditions such as live load, thermal, wind, and earthquake effects. Those conditions shall comply with AASHTO Specifications.

(3) Width

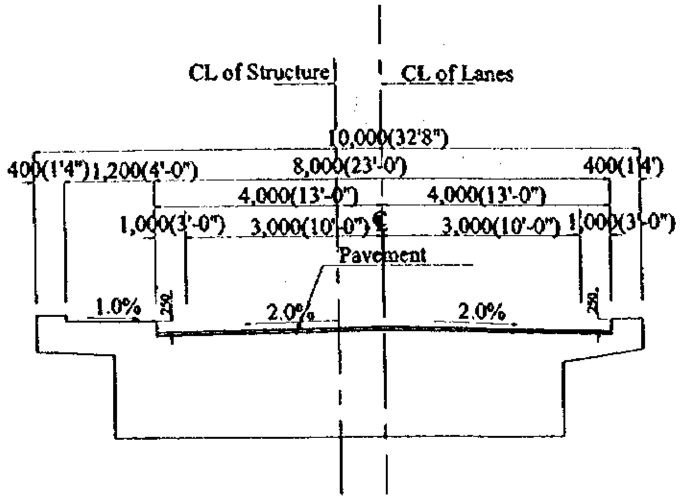
The cross section elements of the new bridge and approach roads shall be about the same as those of the existing ones as summarized below:

Cross Section Elements	The Existing	New Facility
• Bridge		
Carriage-way Width	10'-00" (3.047 m)	3.000m(10'-00")
Shoulder Width	2'-00" (0.609m)at both sides	1.000 m(3'-00") at both sides
Sidewalk	4'-00" (1.219m) at one side	1.200m (4'-00")at one side
Total Width	32'-7" (9.931 m)	10.00m (32'-8")
• Approach Road		
Nos. of Lane	2	2
Lane Width	10'-00" (3.048m)	3.000m(10'-00")
Shoulder Width	(0.608m)at sidewalk side 4'-00" (1.216m) at fill side	0.600m(2'-00") at sidewalk side 1.200m (4'-00") at fill side
Sidewalk	4'-00" (1.216m) at one side	1.200m (4'-00") at one side
Formation Width	33'-00" (10.058m)	10.030m(33'-00")

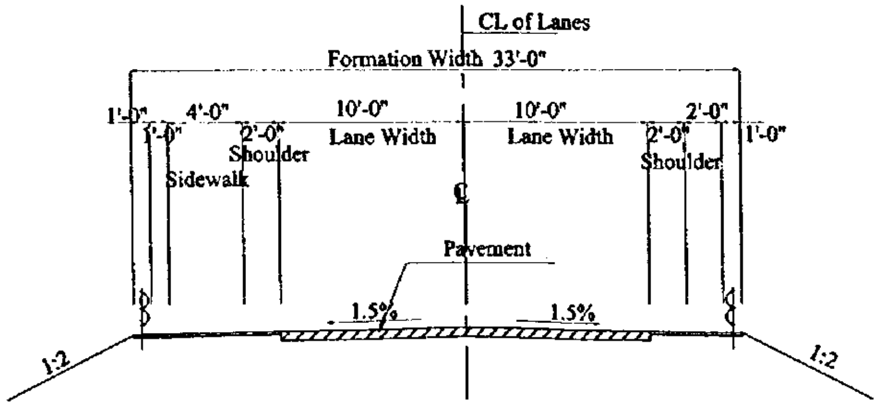
The applicable typical cross sections in the study from the above are depicted in the following figures.

Typical Cross Section of New Bridge Width

Unit : Millimeter



Typical Cross Section of Approach Roads, if existing re-used



2.2.2 Selection of Optimum Project Scheme

(1) Selection Procedure of Optimum Scheme

In the Project, there are several alternatives for each component of the scheme such as bridge crossing site, type of superstructure, type of foundation and location of foundation. In this section, all the possible alternatives of each component are evaluated to select the suitable alternative(s) and an optimum component. Based on these preliminary selection results, the selected alternatives and an optimum project component are combined to formulate suitable project scheme alternatives and these alternatives are evaluated. Accordingly an optimum project scheme is selected from construction cost, durability, construction period, maintenance aspects. The procedure of selecting an optimum project scheme is depicted in Figure-1.

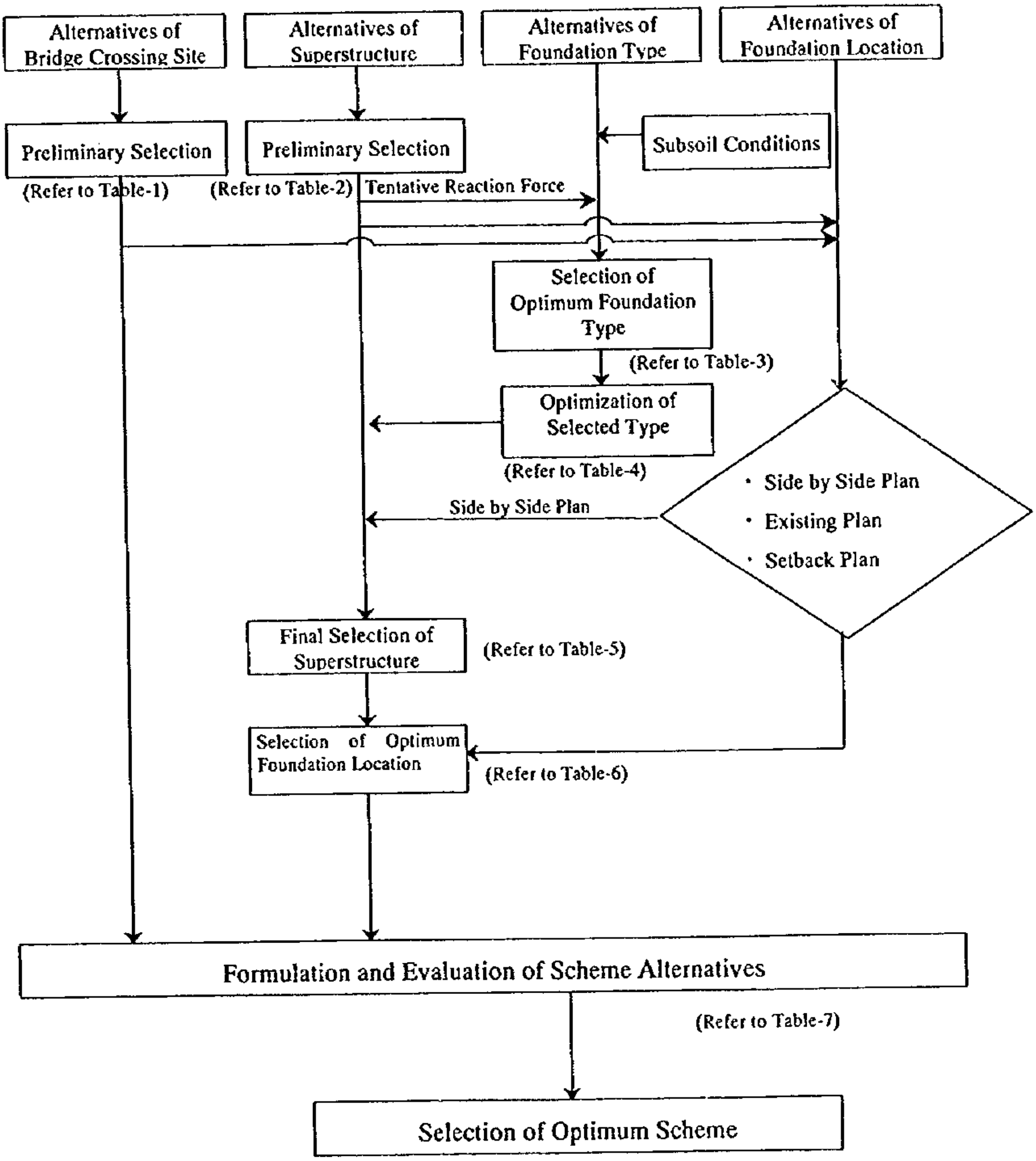


Fig.1 Flow Chart of Selection of Optimum Scheme

(2) Preliminary Selection of Bridge Crossing Sites

There are three bridge crossing site alternatives as shown in Fugure-2.

Alt-1:Shifting Plan North-West Side of which alignment is 25m apart from the existing bridge and in parallel with the existing alignment,

Alt-2:Original Location Plan As Same As Existing of which a new alignment is as same as the existing, and

Alt-3:Shifting Plan South- East Side of which alignment is 25m apart from the existing bridge and in parallel with the existing alignment.

Each of the alternatives is evaluated from various aspects such as construction cost, constructability, construction period, possible difficulty of project implementation, project maintenance, land acquisition and compensation, and engineering aspect. The evaluation results are tabulated in Table-1.

Among the three alternatives, Alt-1 North-West Side Shifting Plan and Alt-2 Original Location Plan As Same As Existing were selected as suitable alternatives for further evaluation. But Alt-3 was not considered further because of difficulty in the land acquisition on Airai side.

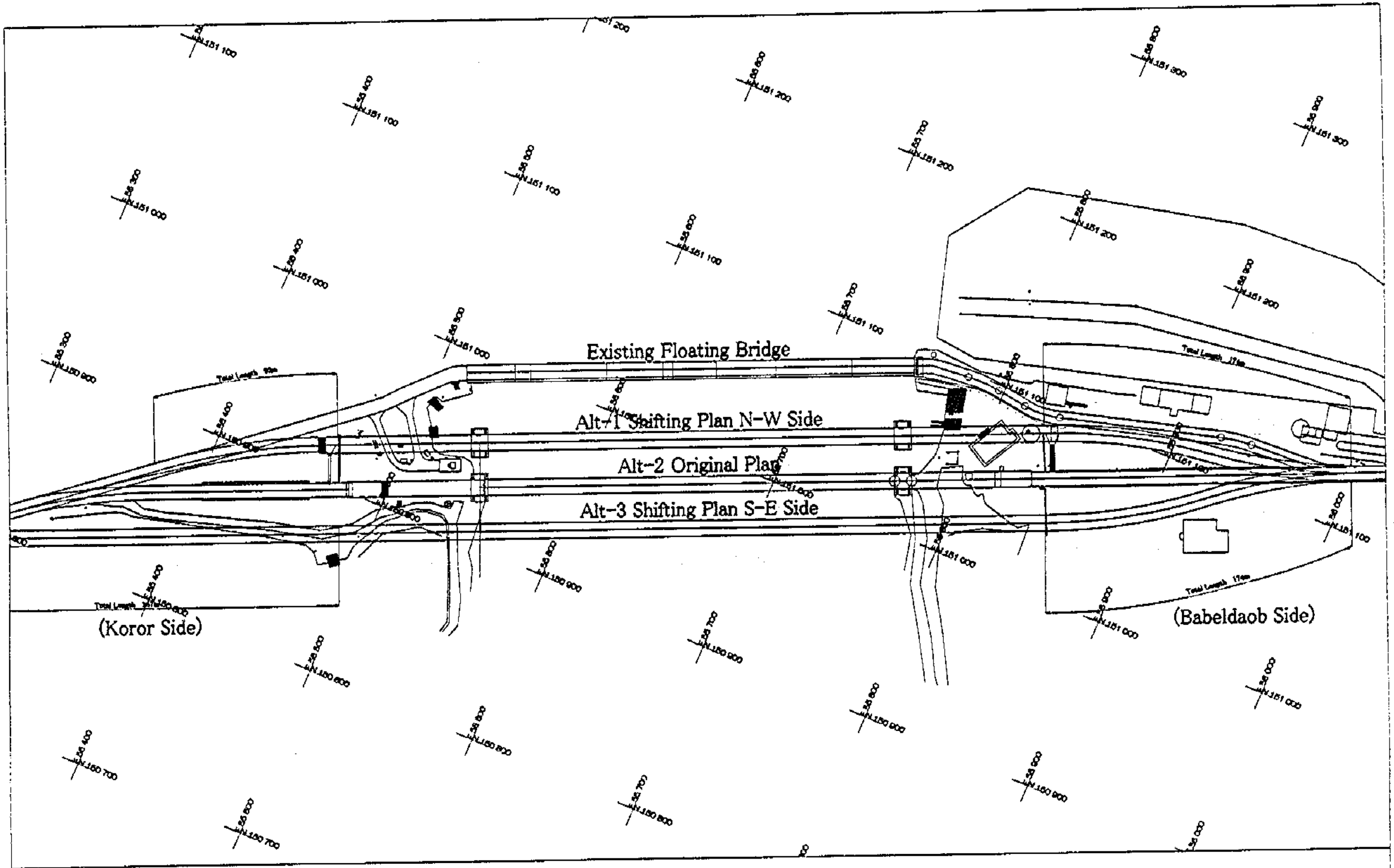


Figure-2 Bridge Site Alternatives

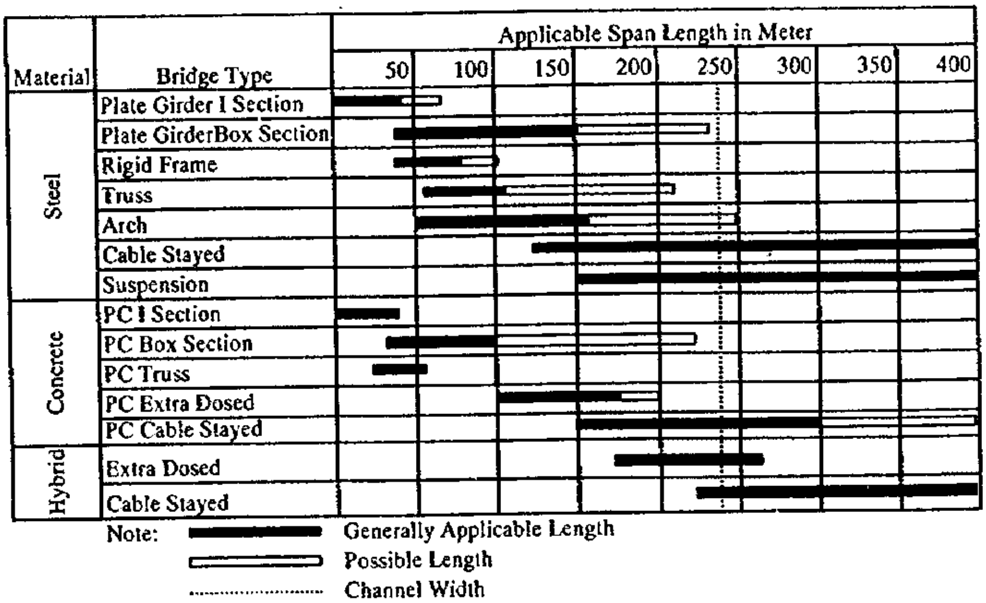
Table-1 Comparative Study of Bridge Location Alternatives.

Alt.	Evaluation Items		Evaluation	Overall Rating
Alt-1 Shifting Plan North- West Side	Construction Cost	Bridge	Bridge cost is cheaper than that of Alt-2 because of no obstructions of the existing pile caps. ◎	Selected
		Approach Road & Miscellaneous	Additional works of both side approach roads, detour roads for maintaining existing traffic and shore protections require additional cost. ×	
	Constructability		The worst among three Alternatives because of many work items. ×	
	Construction Period		The longest period among three Alternatives because of many work items. ×	
	Treatment of the Existing Bridge		No influence for project implementation. ◎	
	Maintenance Aspect		Considerably required during and after construction. ×	
	Land Acquisition & Compensation		Land acquisition and compensation are necessary. However, land acquisition is easier than that at the southern side. ×	
	Others		The worst adverse environmental effects. ×	
Alt-2 Original Plan As Same As the Existing	Construction Cost	Bridge	The existing obstacle slightly increases construction cost of new bridge. △	Selected
		Approach Road & Miscellaneous	The existing approach roads can be utilized. Necessary cost for approach roads is very small compared with shifted plans. ◎	
	Constructability		Construction is the easiest among three alternatives except removal of the existing bridge. ◎	
	Construction Period		Construction period is the shortest among three alternatives except that for removal of the existing bridge. ◎	
	Treatment of the Existing Bridge		Prior to new bridge construction, it is necessary to remove the existing bridge. ×	
	Maintenance Aspect		Maintenance is the easiest among three alternatives. ◎	
	Land Acquisition & Compensation		Land acquisition and compensation are not necessary. ◎	
	Others		No special problem for environment. ◎ Alignment is better than shifted plans. ◎	
Alt-3 Shifting Plan South East Side	Construction Cost	Bridge	Almost the same conditions as Alt-1, new bridge construction cost is less than Alt-2. ◎	Discarded
		Approach Road & Miscellaneous	Additional construction cost for new approach roads (L = 441 m) and protection around piers are necessary. However, detour for existing traffic is not necessary. ×	
	Constructability		Bridge construction is easier than Alt-2. However, since detour is not necessary, this plan is better than Alt-1. △	
	Construction Period		Bridge construction period is relatively shorter than Alt-2. However, approach road and shore protection works require more total period than that of Alt-2. ×	
	Treatment of the Existing Bridge		No influence for project implementation. ◎	
	Maintenance Aspect		Maintenance of approach roads and shore protection are required, so Alt-3. is worse than Alt-2. ×	
	Land Acquisition & Compensation		Land acquisition is necessary at the both sides. Especially land acquisition and compensation at Airai side are very difficult. ×	
	Others		Reverse curve in both approaches is not desirable. Environmental considerations are required for excavation and embankment. ×	

Legend: ◎:Excellent , ○:Good, △:Fair, ×:Poor

(3) Preliminary Selection of Bridge Types

A bridge type generally depends on an indispensable span length which in turn governs the structural system. The following table shows the relation between indispensable span length and bridge type applicable in the present bridge engineering practice.



Taking into account topography at the KB bridge site, the required span length of a new KB bridge is about 240m. Hence, following possible alternatives are considered into the preliminary selection of the bridge types referring to above table. It is noted that a steel cable bridge requiring the total bridge length of about 480 m to balance the weight is not economical, so that hybrid cable stayed bridge, consisting of steel girder at the center span and PC box girder at the side span is selected mainly taking into account the unbalanced span arrangement of 80 m + 241 m + 80 m.

	No.	Bridge Type	Span Arrangement in Meter
Steel	1	3 Span Continuos Box Girder w/ Steel Deck	80+241+80
	2	Half through Type Balanced Arch	80+241+80
	3	Nielsen system Lohse + Plate girder	80+241+80
	4	Suspension Bridge + Plate Girder	80+241+80
Concrete	5	5 Span Continuos PC Box Girder	59.5+94+94+94+59.5
	6	3 Span Continuos PC Box Girder	80+241+80
	7	PC Cable Stayed Bridge	80+241+80
Hybrid	8	Extra Dosed Bridge	80+241+80
	9	Cable Stayed Bridge	80+241+80

Based on the evaluation of each alternative from various view-points such as construction cost, constructability, structural aspect, construction period, maintenance aspects as summarized in Table-2, five(5) alternatives of Alt-2:Balanced Arch, Alt-6: 3 span continuous PC Box girder, Alt-7: PC Cable Stayed Bridge, Alt-8: Hybrid Extra Dosed Bridge and Alt-9: Hybrid Cable Stayed Bridge are selected for the further study on the selection of an optimum bridge type.

(4) Alternative Study of Foundations

(a) Selection of Optimum Foundation Type

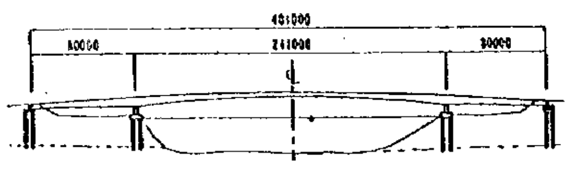
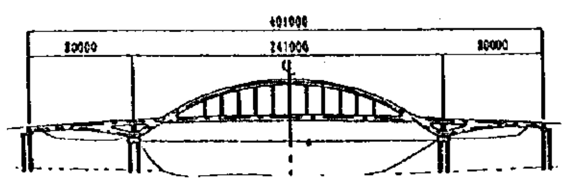
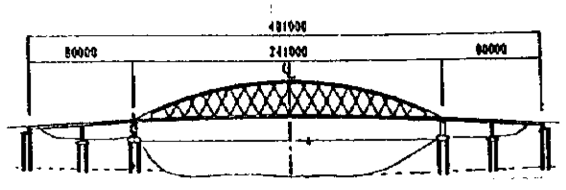
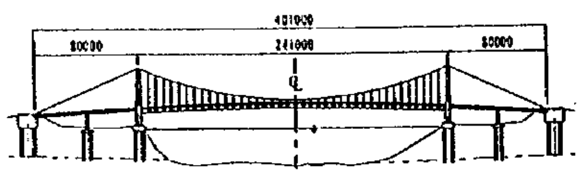
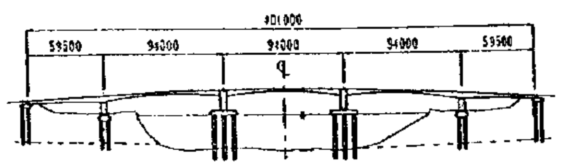
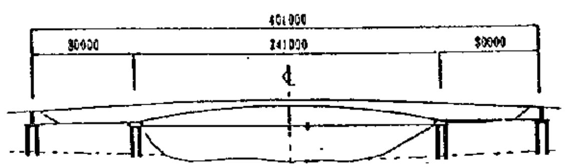
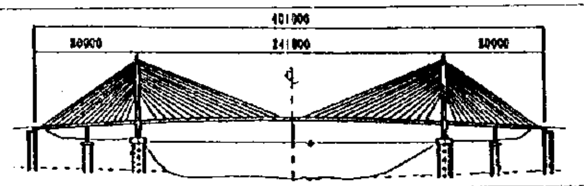
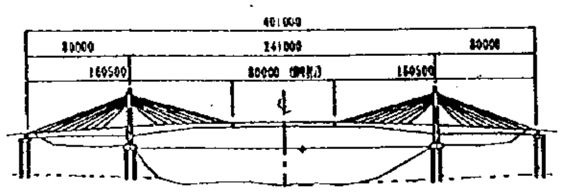
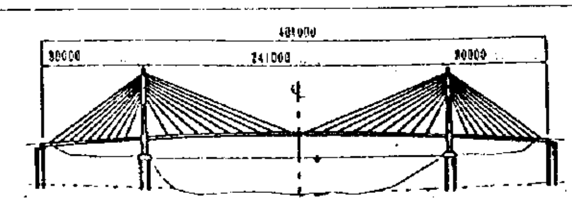
Considering the geological conditions at the site (overlain coral fragments with some layers of sandy clay and underlain bed rock of andesite) and the magnitude of reaction force due to superstructure, the open caisson and cast in place RC pile by all casing method were nominated as the alternatives of foundation type. Based on comparison results of these two alternatives from construction cost, constructability, construction period and environmental aspects as tabulated in Table-3, it is concluded that cast in place RC pile type is superior to open caisson due to less construction cost and shorter construction period.

(b) Optimization of Selected Type

Based on the above results, the optimization study of the cast in place RC pile by all casing method was done to select the most appropriate one. In the study, 2.0 m and 1.5m diameter of the cast in place piles were compared as shown in Table-4.

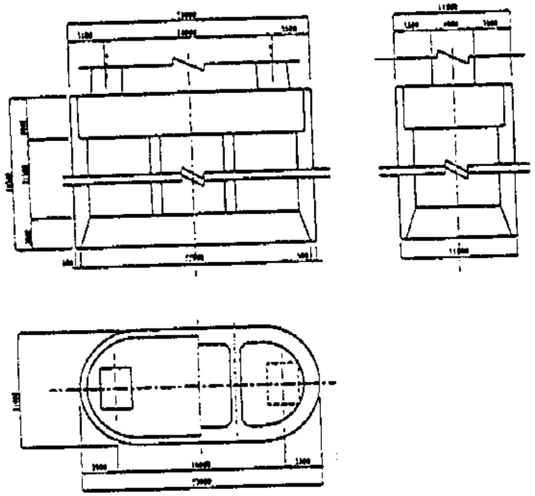
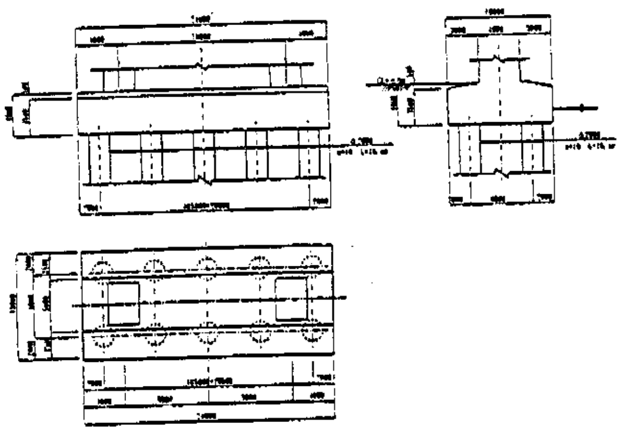
The cast in place RC pile by all casing method with 2.0 m diameter was selected for less construction cost and shorter construction period.

Table-2 Preliminary Selection of Bridge Type

Type	Alt.	Concept Plan	Evaluation Items: Construction Cost	Evaluation Items: Easy Construction	Evaluation Items: Structural Aspect	Evaluation Items: Construction Period	Evaluation Items: Maintenance	Similar Projects: Japan	Similar Projects: World	Overall Rating
Steel Bridge	Alt.1 3 Span Continuous Box Girder		The unit steel weight is 870kg/m2 and the most expensive among the alternatives Construction cost ratio 1.27[×]	Erection method is cantilever using erection nose and barge. Transportation and handling of large block of steel member is not easy. [×]	Less aerodynamic stability[×]	About 20 months [◎]	The area to be painted is the largest among the steel bridge and expensive maintenance cost. [×]	Kaida S=250m, 1991,Hirosina Namihaya S=250m Osaka Tokyo Bay S=240m,1996, Chiba	Costa E SilvaS=300m,1975 Brazil Sava II S=261m,1977, Yugoslavia Zoo S=259m,1966, Germany	Discarded
Steel Bridge	Alt.2 Balanced Arch		The unit steel weight is 780kg/m2 and this type is relatively cheaper than the other alternatives. Construction cost ratio is 1.13[△]	Erection method of center span is cable erection and is required high technique.[×]	High aseismicity and aerodynamic stability [◎]	About 22 months [◎]	Less paint area than Alt-1 but poor maintenance than concrete bridge [×]	Shinkizugawa S=305m,1993, Osaka Kisiwada S=255m,1993 Osaka Imariwann S=250m,1997 Saga	Fremont L=382m,1972, USA Port Mann L=365m,1964, Canada Roose Velt Lake L=329m,1990, USA	Further Study
Steel Bridge	Alt.3 Nielsen System Lohse + Plate Girder		The unit steel weight of 830kg/m2 is relatively light among the steel bridge alternatives and this type is economical. Construction cost ratio is 1. 20 [×]	Center span is launched at one time using a barge but ocean transport of a whole bridge is high risk.[△]	Stable bridge but less durability of deck slab [△]	About 18 months and shortest among the alternatives [◎]	Less paint area than Alt-1 but poor maintenance than concrete bridge.[×]	Shinhamadera S=254m,1991, Osaka Nisinomiya Bay S=252m,1993, Hyogo Onase S=236m,1994, Kyoto	Van Brienenoord L=287m,1965, Netherlands	Discarded
Steel Bridge	Alt.4 Suspension Bridge + Plate Girder		Total steel weight is less than others but anchorage increase total cost. Construction cost ratio is 1.14[△]	The bridge composes of many members and so not so easy work at job site.[×]	Many fatigue members and poor stability of vibration and aerodynamisity [×]	About 28months [△]	Very poor maintenance aspect [×]	Akashi Ohasi S=1990m,1998 Hyogo Minami bisannseto S=1100m1988 Kagawa Kurushima S=1030m,1999 Ehime	Akshi Ohasi S=1990m,1998 Japan Great Belt EastS=1624m 1996 Denmark Humber Bridge S=1410m,1981, UK	Discarded
Concrete Bridge	Alt.5 5 Span Continuous PC Box Girder		The superstructure is the most economical but difficult work of sea pier under water depth of 30m and max velocity of 6 nots. Construction cost ratio is 1.13[△]	The superstructure is erected by cantilever method and the 2 sea piers is constructed using SEP which encounters difficulty. [×]	The superstructure is stable but stability of the sea pier is questionable. [×]	About 32 months. Sea condition affect construction schedule.[×]	The most superior among the Alternatives.[◎]	Hamana S=240m, 1976, Shizuoka Hikone S=236m, 1975, Yamaguchi Urato S=230m,1972, Kouchi	Raftsunded S=296m, 1996 Norway Gate Way S=260m,1986 Austraria Varodd S=260m, 1994 Norway	Discarded
Concrete Bridge	Alt. 6 3 Span Continuous PC Box Girder		This Alternative is the same type as the failed KB bridge. Construction cost ratio is 1.07[◎]	The superstructure is erected by cantilever method. The largest concrete volume among the concrete bridge alternatives [△]	Durability of the bridge is superior but deflection at mid point of the center span due to long term creep is possible defect.[×]	About 30 months [×]	Superior maintenance except center hinges [◎]	Hamana S=240m, 1976, Shizuoka Hikone S=236m, 1975, Yamaguchi Urato S=230m,1972, Kouchi	Raftsunded S=296m, 1996 Norway Gate Way S=260m,1986 Australia Varodd S=260m, 1994 Norway	Further Study
Concrete Bridge	Alt. 7 3Span PC Cable Stayed Bridge		The concrete volume is decreased by provision of stayed cables and so relatively cheaper than other alternatives. Construction cost ratio is 1.13[△]	Erection method is cantilever erection for center span and staging for side span. [△]	Aerodynamic stability is improved compared with hybrid cable stayed bridge. [◎]	About 32 months [×]	Superior maintenance except stayed cables and anchorage [△]	Itoshima S=260m,1997 Kagoshima Tokachi S=251m, 1996 Hokkaido Yobuko S=250m,1989 Saga	Skarnsundet S=530m,1991 Norway Daini jyuukei S=444m, 1995, China Ingeniero Carlas S=440m,1983 Spain	Further Study
Hybrid Bridge	Alt. 8 3 Span Extra Dosed Bridge		Applicable span length of PC cable stayed bridge is 200m. Hence, hybrid type is applied to extend applicable span length. Construction cost ratio is1.00[◎]	Erection method is cantilever erection for center span and staging for side span. Whole steel span is launched using erection nose. [△]	Because of high rigidity of girder, aerodynamic stability is improved compared with cable stayed bridge. [◎]	The shortest construction period (26 months) among the concrete bridge alternatives [△]	Stayed cables and steel span require maintenance [△]	Kisogawa S=275m, Aichi Ibigawa S=271m, Aichi	None	Further Study
Hybrid Bridge	Alt.9 3Span Cable Stayed Bridge		Relatively economical and construction cost ratio is 1.04.[◎]	The erection method is almost the same as that in Alt-7.[△]	Less aerodynamic stability and a countermeasure is required.[×]	24months [△]	Stayed cables and steel span require maintenance.[×]	Tatara S=890m Hiroshima Ikuchi S=490m,1991 Hirosima Tkachi chuou S=250m 1988 Hokkaido	Tatara S=890m Hiroshima Normandy S=856m,1994, France Houho S=602m, 1993 China	Further Study

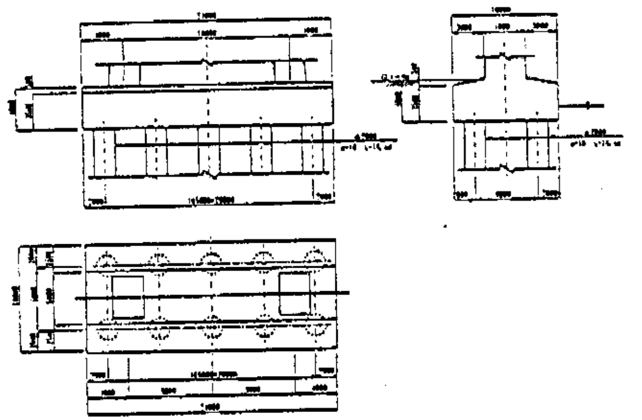
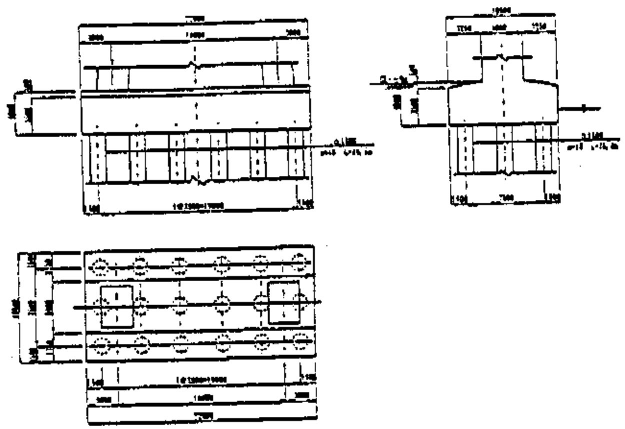
Legend: ◎:Excellent, O:Good, △:Fair, ×:Poor   Note: Construction cost ratio is construction cost of a specific Alt against cost of Alt.7.

Table-3 Alternative Study of Foundation Types

Alternatives	Dimensions	Evaluation Items	Evaluation	Overall Rating
Alt-1 Open Caisson		Construction Cost	Cost of this alternative is about 40% higher than that of Alt-2. [×]	Discarded
		Easy Construction	Bearing stratum can be visually ascertained. To keep construction accuracy of the vertical axis is difficult due to one side earth pressure. [×]	
		Construction Period	Construction period is 7 months for completion of 1 caisson. In case of encountering massive and hard corral stratum during sinking, additional time will be required. [×]	
		Environmental Effect	Noise, air pollution and vibration are not much problems, but treatment of the excavated material shall be paid special attention. [○]	
		Others	This method is not applicable to construction of foundation at the same location as the existing pile cap. [×]	
Alt-2 Cast in Situ Concrete Pile (All Casing Method)		Construction Cost	This alternative is 40% cheaper than that of Alt-1. [○]	Taking into account cheaper construction cost and shorter construction period, Alt-2 was selected
		Easy Construction	All casing method can be undertaken using simple and standard equipment. This method is applicable to massive and hard corral stratum. [○]	
		Construction Period	Construction period to complete one foundation is about 3.5 months without any special problems. [○]	
		Environmental Effect	Since bentnite preventing from earth wall collapse is not required and soil movement and noise problem, air pollution and vibration are minimal. [○]	
		Others	This methods can be applied to construction of new pile cap at the same location as the existing pile cap. [○]	

Legend: ◎:Excellent, ○:Good, △:Fair, ×:Poor

Table-4 Optimization of Selected Type

Alternatives	Dimensions	Evaluation Items	Evaluation	Overall Rating
Alt-1 Cast in Situ Concrete Pile with a Diameter of 2.0M by All Casing Method		Construction Cost	About 8% cheaper than Alt-2. [◎]	Taking into account cheaper construction cost and shorter construction period, Alt-1 was selected.
		Easy Construction	Pile diameter of 2m is almost upper limit of this method and construction equipment required are also limited in the market. However, there is no special problems since many cases have been experienced. [Δ]	
		Construction Period	Excavation rate of casting pile is 1.7 days/1 no. (length of pile L = 26.5m, Diameter D = 2.0m), it takes 17 days for 10 nos. to complete this alternative. Therefore, this alternative is shorter about two weeks including movement, installation of equipment in comparison with 1.5m diameter. [◎]	
		Environmental Effect	No special difference between two alternatives.	
		Others	Careful attention for lifting up cage bar during installation of bars is required.	
Alt-2 Cast in Situ Pile with a Diameter of 1.5M by All Casing Method		Construction Cost	About 8% higher per one footing than Alt-1. [×]	Discarded
		Easy Construction	No special problems for procurement of materials and equipment and construction. [◎]	
		Construction Period	Excavation rate of casting pile is 1.4 days/1 no. (length of pile 26.5m, Diameter 1.5m). The number of pile in this alternative is 18 and it takes 25 days to complete. Therefore, two weeks longer than Alt-1 to complete. [×]	
		Environmental Effect	No special difference between two alternatives	
		Others		

Legend: ◎:Excellent, ○:Good, Δ:Fair, ×:Poor

(5) Optimum Bridge Type Selection

Each of the alternatives selected through the Preliminary Selection of Bridge Types is scrutinized with the structural analysis, preliminary assessment of construction method, cost estimate, construction period and identification of possible environmental adverse effects and maintenance cost and level of maintenance technique required. The study results are tabulated in Table-5.

With the results of above study, Alt-4:Hybrid Extra Dosed Bridge was selected as the optimum alternative for the Project for A New KB Bridge Construction.

(6) Alternative Study of Foundation Locations

For the original location plan with the same alignment as the existing, there are three alternatives of the foundation location.

Alt-1: original plan as the same location as the existing pile cap is to construct the cast in situ concrete pile with a diameter of 2.0 m using special drilling equipment (rotating all casing method) which is applicable for, even though new piles hit the existing driven RC piles (45*45cm).

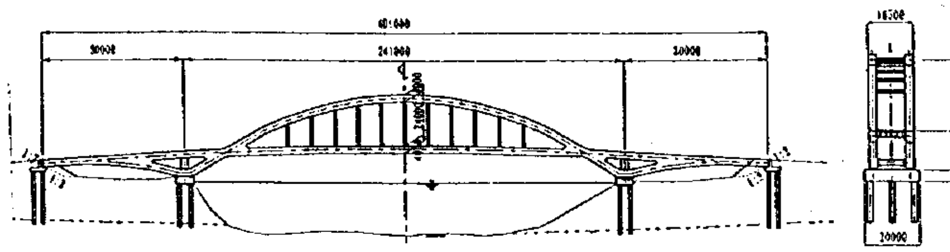
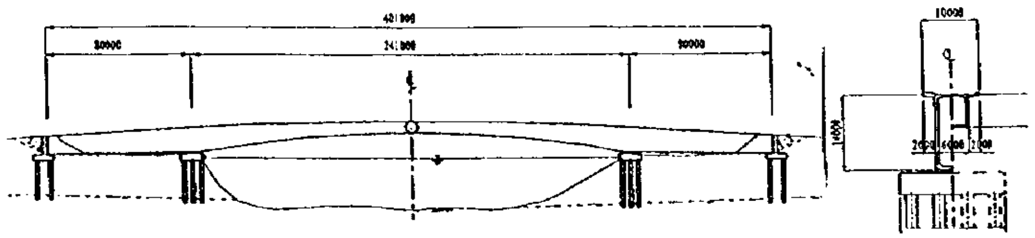
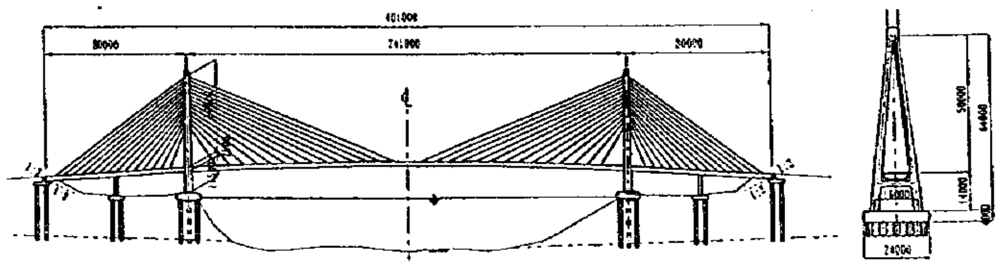
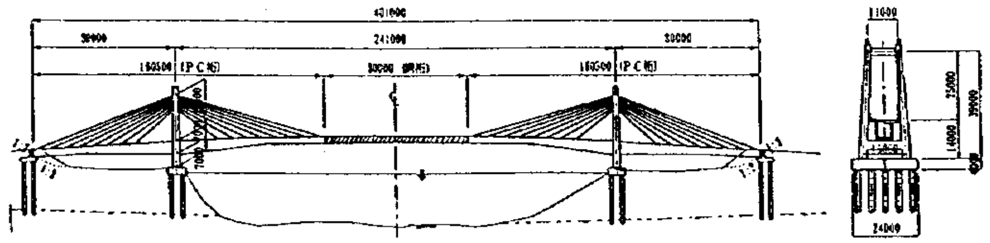
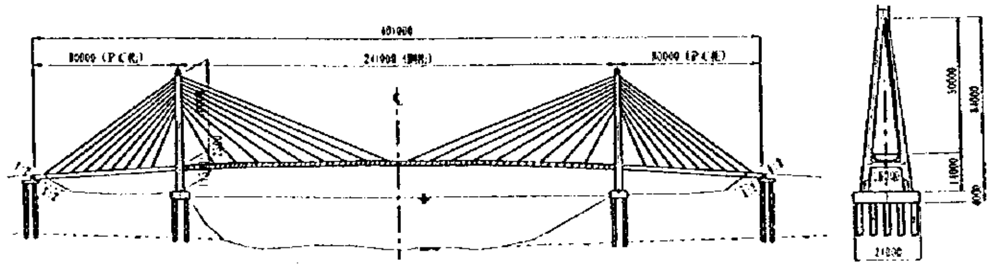
Alt-2: Portal type pile cap avoiding the existing pile cap is to construct new pile caps separately on each side of the existing pile cap using standard all casing drilling equipment and to connect each other by struts.

Alt-3: Setback plan avoiding the existing pile cap is to construct a new pile cap at the back of the existing pile cap using standard all casing drilling equipment. This alternative needs longer span length of the supper-structure than the other two alternatives.

Each of the above alternatives is evaluated from several view points such as construction cost, constructability, structural aspect, construction period, environmental aspect and the results are summarized in Table-6.

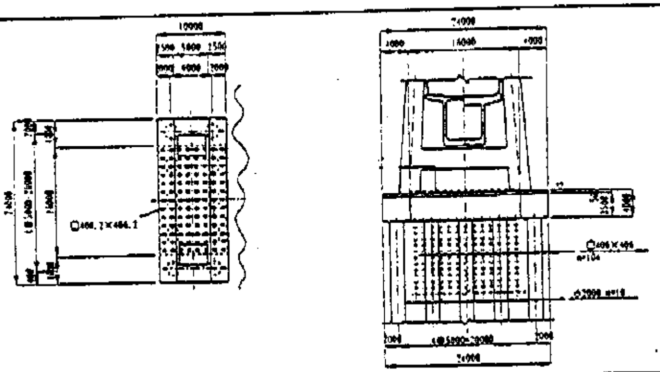
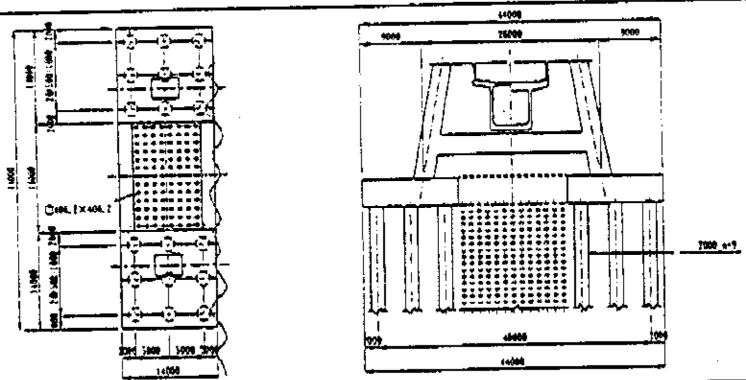
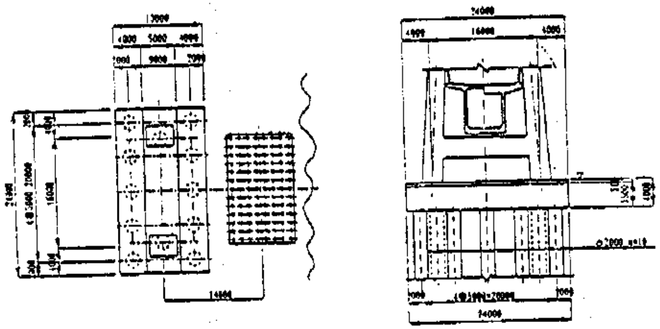
From the evaluation results, it is concluded that Alt-1 Original Location Plan as the same location as the existing pile cap is superior to the others from construction cost and construction period aspects.

Table 5 Optimum Bridge Type Selection

Alt.	General View	Evaluation Items	Evaluation	Rating Results
Alt-1 **Half Through Type Steel Balanced Arch**		Construction Cost	Among the alternatives, the most expensive and 13% higher than Alt-4. ×	Discarded
		Easy Construction	Almost all bridge parts are fabricated at shop and so easy quality control. ◎	
		Structural Aspect	Span arrangement is not balanced and deck slab is not durable. △	
		Construction Period	The shortest construction period with 22 months. ◎	
		Maintenance	The huge maintenance work load for repainting ×	
		Environmental Aspect	Under Construction: No special problems After Completion: Splash of paint should be taken care in repainting. ×	
		Overall Evaluation	The highest construction cost and maintenance cost among the five alternatives. ×	
Alt-2 **3 span Continuos PC Box Girder**		Construction Cost	Construction cost of this Alt. is about7% higher than that of Alt-4 △	Discarded
		Easy Construction	Huge volume concrete is used, so that strict quality control is required. ×	
		Structural Aspect	Possible defect is displacement of span center due to creep effect. ×	
		Construction Period	Construction period is about 30 months. ×	
		Maintenance	Among 5 alternatives, the best and almost maintenance free. ◎	
		Environmental Aspect	Under Construction: No special problems After Completion: No special problems ◎	
		Overall Evaluation	The construction cost is about 7% more expensive than that of Alt-4 but the most superior alternative from maintenance aspect. Disadvantage of this alternative is a possible structural defect of displacement at span center due to long term creep. ×	
Alt-3 **PC Cable-Stayed Bridge.**		Construction Cost	Construction cost is about 12% higher than Alt-4. ×	Discarded
		Easy Construction	Construction is easier than Alt-2. due to less concrete volume and easy adjustment of camber by stay. O	
		Structural Aspect	Uplift prevention is required, but structure system is stable. O	
		Construction Period	The longest construction period with 32 months. ×	
		Maintenance	Maintenance of stay cables and anchors requires sophisticated and high level technique. △	
		Environmental Aspect	Under Construction: No special problems After Completion: No special problems O	
		Overall Evaluation	This alternative is about 12% more expensive that Alt-4 but less maintenance cost than Alts-4 &5. Disadvantage of this alternative are the longest construction period and mitigation measures are required for cable vibration due to wind Sophisticated maintenance and possible replacement for mitigation apparatus for cable vibration with high level technique△	
Alt-4 **Hybrid Extra Dosed Bridge.**		Construction Cost	This alternative is the most economical among 5 alternatives. ◎	Selected
		Easy Construction	Less cables and less concrete volume than others makes easy construction. And stress adjustment of stay cable is easier than that of cable stayed. O	
		Structural Aspect	Higher rigidity of girder than cable stayed bridges makes structure stable including aerodynamics. ◎	
		Construction Period	Construction period is 26 months which is relatively short. △	
		Maintenance	Less steel portion reduces maintenance work load. Maintenance technique required is standard. O	
		Environmental Aspect	Under Construction: No special problems After Completion: No special problems O	
		Overall Evaluation	This is the most economical and less construction period alternative. Higher aerodynamic stability than cable stayed bridges. ◎	
Alt-5 **Hybrid Cable-Stayed Bridge.**		Construction Cost	Construction cost is 4% higher than Alt-4. O	Discarded
		Easy Construction	Adjustment of stay cable stress is more difficult than Alt-4 due to flexible steel girder but quality control is easier than Alt-4. △	
		Structural Aspect	Stability for wind is worse than Alt-3 due to light weigh of steel girder. △	
		Construction Period	About 24 months. O	
		Maintenance	Steel girder requires considerable maintenance work loads for repainting. △	
		Environmental Aspect	Under Construction: No special problems After Completion: Splash of paint must be taken care during repainting. ×	
		Overall Evaluation	Shorter construction period than Alt-4 , but more expensive of initial cost and maintenance cost than Alt-4. Mitigation measures for cable vibration and sophisticated maintenance and possible replacement for these with high level technique are required as same as Alt-3. O	

Legend: ◎:Excellent , O:Good, △:Fair, ×:Poor

Table-6 Alternative Study of foundation Locations

Alternatives	Dimension	Evaluation Item	Evaluation	Overall Rating
Alt-1 Original Plan as the same location as the existing		Construction Cost	Total Cost (superstructure and substructure) is the most economical among three alternatives. [◎]	Taking into account cheaper construction cost and shorter construction period, Alt-1 was selected.
		Easy Construction	Among 10 piles required, 6 piles are installed by rotating all casing method with cutter and remaining 4 piles are installed by normal casing bored piling method. Special equipment is necessary. [Δ]	
		Structural Features	Structural features are the same as Alt-3. [○]	
		Construction Period	Construction period is the shortest among the others. [◎]	
		Environmental Aspect	Noise, air pollution and vibration are minimal. Treatment of construction wastes must be considered. [○]	
		Others	No special difference between Alt-1& Alt-3. [○] No special problems of maintenance. [○]	
Alt-2 Portal Type Pile Cap (Side by side the existing pile cap)		Construction Cost	Total cost is about 12% more expensive than that of Alt-1 including shore protection. [Δ]	Discarded
		Easy Construction	Half of piles are located on corral shelf. Hence, temporary sheet piles are required. Construction area is divided into two portions, which in turn cause the worst constructability. [×]	
		Structural Features	Horizontal force is acted to strut laterally due to inclined tower. [×]	
		Construction Period	Quality of construction work is the biggest amount among the others and the construction period is also the longest. [×]	
		Environmental Aspect	Noise, air pollution and vibration are minimal. Treatment of construction wastes has to be taken into account. Also, preservation of corral shelf is required under consideration. [×]	
		Others	From aesthetic point of view, this Alt. is the worst. [×]	
Alt-3 Set Bak-Plan (At the back of the existing pile cap)		Construction Cost	Cost of the substructure is 11% cheaper than Alt-1, however, cost of superstructure is 23% higher. Then, total cost is 16% more expensive than Alt-1 [×]	Discarded
		Easy Construction	All construction activities can be done on land and so constructability is the best. [◎]	
		Structural Features	Aesthetic structural features is the same as Alt-1. [○]	
		Construction Period	Construction period requires 2 month longer than that of Alt-1.(28 months). [Δ]	
		Environmental Aspect	Environmental effect under construction is minimal and the same as Alt-1. [○]	
		Others	From aesthetic view no special difference between Alt-1 & Alt-3. [○] No special problems of maintenance. [○]	

Legend: ◎:Excellent, ○:Good, Δ:Fair, ×:Poor

(7) Selection of Optimum Project Scheme

In addition to the study results in the above sub-sections, necessity of the approach road and other related facilities such as temporary detour road and shore protection work are considered in formulating the project scheme alternatives. Based on combination of these elements, two project scheme alternatives were prepared as depicted in Fig.-3 and as tabulated below:

Alt.	Scheme Component				Related Facilities		
	Crossing Site	Super structure	Foundation Location	Foundation Type	Approach Road	Temporary Detour Road	Shore Protection
Alt-1	Shifting Plan North-West Side	Hybrid Extra Dosed Bridge	Beside the existing	Cast in Situ Pile by All Casing Method	Required	Required	Required
Alt-2	Original Location Plan		Same Location as the existing	Cast in Situ Pile by Rotating All Casing Method	Not Required	Not Required	Not Required

The evaluation of these alternatives was done from construction cost, constructability, construction period, maintenance, and other aspects such as land acquisition and compensation. The results are shown in Table 7.

As indicated Table 7, it is obvious that Alt-2: Original Location Plan is superior to Alt-1: Shifting Plan from view points of all the evaluation items except demolition of the existing bridge. The Government of Palau has however accepted demolition of the existing bridge under the recipient country's obligations. Hence, it is concluded that hybrid extra dosed bridge rested on cast in situ concrete pile with a diameter of 2.0m located along the same location as the existing bridge is an optimum project scheme for the Project for Construction of A New KB Bridge.

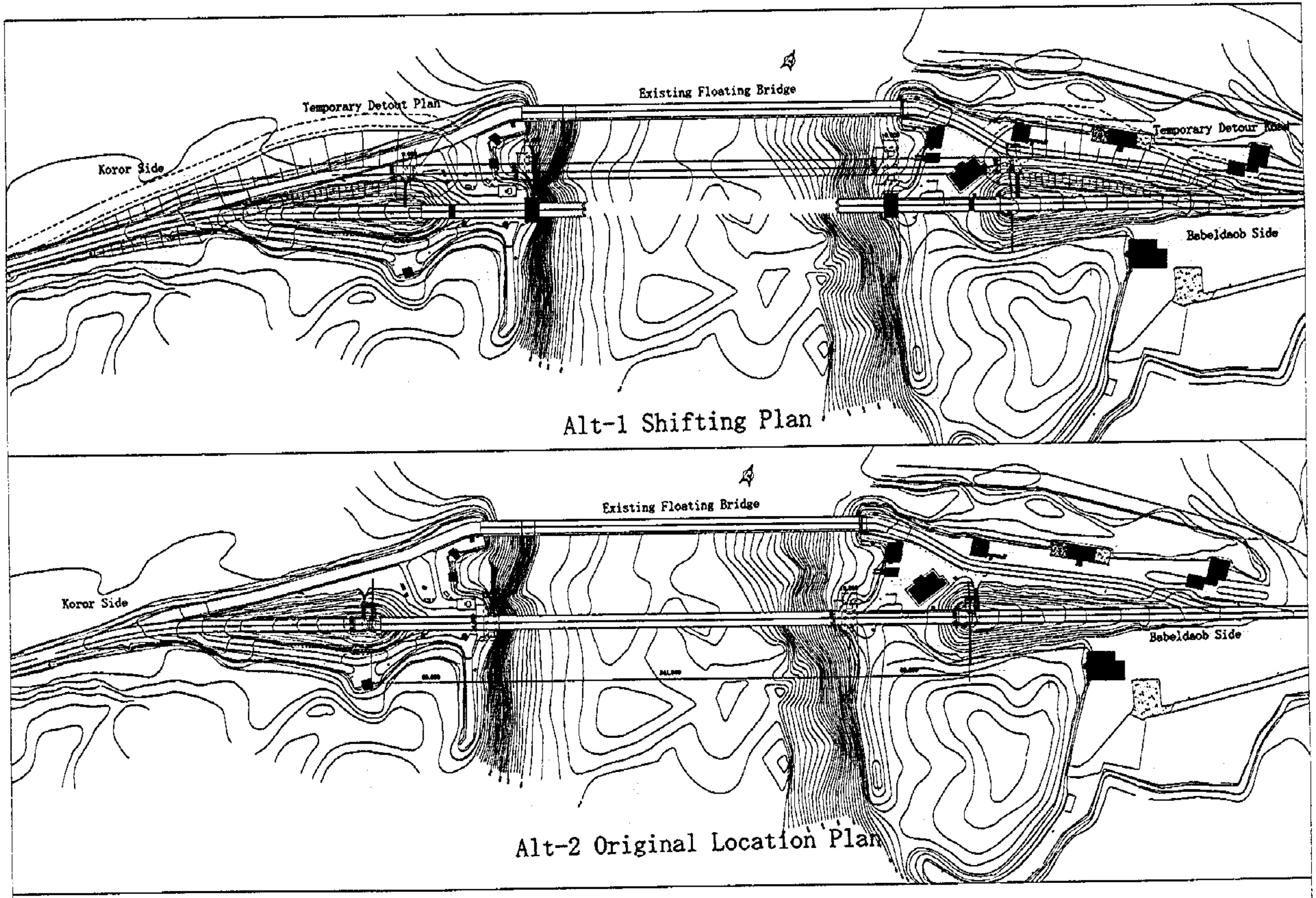


Figure-3 Project Scheme Alternative

Table-7 Comparative Study of Project Scheme Alternatives

Alt.	Evaluation Items		Evaluation		Overall Rating
Alt-1 Shift Plan North West Side	Construction Cost	Bridge Cost	Bridge cost of superstructure and substructure is about 1% cheaper than that of Alt-2.	Bridge cost is slightly cheaper than Alt-2 but the total cost is 12 % more expensive than Alt-2 because of additional works of approach roads, temporary detour road and shore protection. [×]	Discarded
		Approach Road	Required and about 8 % additional of bridge cost.		
		Temporary Detour Road	Required and about 3 % additional of bridge cost.		
		Shore Protection	Required and about 1 % additional of bridge cost.		
	Constructability		Worse constructability because of additional works of approach roads, temporary detour road and shore protection. [×]		
	Construction Period		Due to additional works, five months more is required and the total construction period is 31 months. [×]		
	Maintenance		No special difference regarding bridge maintenance. From overall aspect, this plan is inferior to Alt-2 because of additional works [×]		
	Aesthetic Aspect		No special difference between two alternatives in case the existing bridge and approach roads have been demolished. [○]		
	Others	Demolishing Existing Bridge	No influence to the project implementation. [○]	Disadvantages such as compensation and poor alignment are more critical than advantage. [△]	
		Compensation	Land acquisition of 4300sq.m and compensation for five houses are required. [×]		
		Road Alignment	Application of reverse curves in approach roads is not desirable. [×]		
Alt-2 Original Alignment	Construction Cost	Bridge Cost	Bridge cost of superstructure and substructure is about 1% expensive than that of Alt-1.	Superior to Alt-1 because of 12 % cheaper than Alt-1 in the absence of approach roads, temporary detour road and shore protection. [◎]	Selected
		Approach Road	Not necessary		
		Temporary Detour Road	Not necessary		
		Shore Protection	Not necessary		
	Constructability		No special problems except application of special drilling equipment. [○]		
	Construction Period		Five months shorter than Alt-1 and total construction period is about 26 months. [◎]		
	Maintenance		Superior to Alt-1. [◎]		
	Aesthetic Aspect		Superior to Alt-1. [◎]		
	Others	Demolishing Existing Bridge	It is necessary to remove the existing bridge prior to the project implementation. [×]	Relatively superior to Alt-1 [◎]	
		Compensation	No special problems [◎]		
		Road Alignment	No special problems [◎]		

Legend: ◎:Excellent , ○:Good, △:Fair, ×:Poor

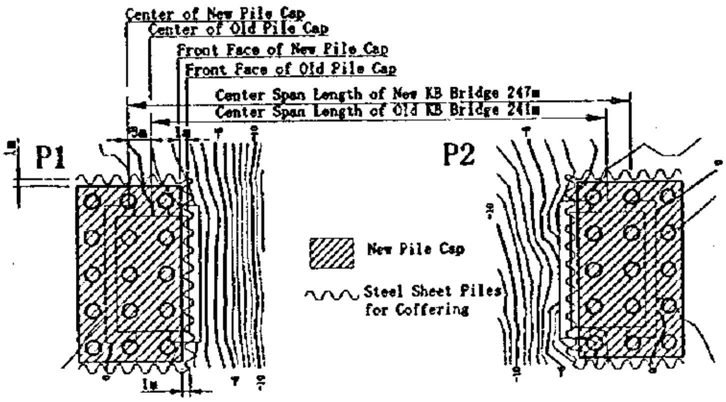
2.2.3 Optimization of Selected Bridge Type

This sub-section presents refinement of the optimum bridge type selected, hybrid cable stayed extra dosed bridge, in terms of center span length, side span length, steel girder length, connection conditions and type of stay cables before proceeding the basic design.

(1) Refinement on Center Span Length

In general, center span length should be shortened as much as possible to economize the bridge cost. In case of a new KB bridge, the center span length is determined taking into account longitudinal dimension of the new pile cap and suitable/reliable cofferdam structure to use in the construction of pile cap in the steep terrain in front of the pile cap.

Based on the pile cap location study, in case of the front face of new pile cap located at the same position as the existing, the cofferdam becomes a large scale structure and has high risk of design change/failure because of the steep terrain in front of the pile cap. Consequently this alternative, that is span length of 245m, was discarded and the second option which is the front face of new pile cap shifted one meter on shore side is selected. In this case, the cofferdam can be constructed using single steel sheet piles with reliability and the center span length is 247 meter (241 m of span length in the existing bridge plus 3m each side) as illustrated below:



(2) Refinement of Side Span Length

This sub-section presents refinement of side span length which is tentatively 80 m in the bridge type selection.

At first, three alternatives changing span ratios from 1:2.5:1, 1:3.0:1, and

1:4.0:1 in the center span length of 247 m are studied as tabulated below:

		Alt-1	Alt -2	Alt-3
Span Arrange-ment	Ratio	1.0:2.5:1.0	1.0:3.0:1.0	1.0:4.0:1.0
	Length	98m+247m+98m	82m+247m+82m	61m+247m+61m
Structural Aspects		-Counter weight is not required at side span. -Stay cable arrangement is unbalanced	-Counter weight is required to prevent up lift at girder end. -Stay cable arrangement is balanced	-A huge volume of the counter weight is required at side span. -Stay cable arrangement is unbalanced
Construction Cost		Total cost is 8% expensive than that of Alt-2.	Most economical alternative	Total cost is 7% expensive than that of Alt-2.
Overall Rating		Discarded	Selected	Discarded

The span arrangement of 82m+247m+82m (span ratio of 1.0:3.0:1.0) was selected as a suitable and economical arrangement.

Based on the above study results, the span arrangement of 82m+247m+82m was further scrutinized by changing the side span length ±5m which is one block length of the PC girder. The pros & cons of each alternative are shown below:

		Alt-1	Alt -2	Alt-3
Span Arrange-ment	Ratio	1.0:2.8:1.0	1.0:3.0:1.0	1.0:3.2:1.0
	Length	87m+247m+87m	82m+247m+82m	77m+247m+77m
Structural Aspects		-Total concrete volume increases compared with Alt-2. -Stay cable arrangement is unbalanced and the quantity increases.	-Total quantities including concrete are the least among three Alternatives. -Stay cable arrangement is balanced.	-A volume of the counter weight increases. -Stay cable arrangement is unbalanced and the quantity increases. -Severe stress condition in bottom slab.
Construction Cost		Total cost is slightly (about 1.6 %) expensive than that of Alt-2.	Most economical alternative	Total cost is slightly (about 1.7 %) expensive than that of Alt-2.
Overall Rating		Discarded	Selected	Discarded

From the above comparison, the span arrangement of 82m+247m+82m is relatively economical and structural stable as an optimum.

(3) Alternative Study of Steel Girder Length

Based on the study results of (1) Refinement on center span length and (2) Refinement of side span length, the alternative study of the steel girder length is conducted to determine the most suitable and economical steel girder length. The alternatives are formulated changing the steel girder length from 72 m to 92 m in the span arrangement of 82m+247m+82m.

	Alt-1	Alt -2	Alt-3
Steel Girder Length	92m	82m	72m
Span Arrangement	82m+247m+82m	82m+247m+82m	82m+247m+82m
Number of Stay Cable Layer	11	12	12
Counter weight of Side Span	22ton/m	24ton/m	27ton/m
Structural Aspect	The worst aerodynamic stability and stress fluctuation of stay cables due live load are bigger than that in Alt-2.	The least stress fluctuation of stay cables and relatively stable aerodynamic.	Better aerodynamic stability but stress fluctuation of stay cables are bigger than that in Alt-2.
Construction Cost	Total cost is about 1% more expensive than that of Alt-2.	Most economical alternative	Total cost is about 2% more expensive than that of Alt-2.
Overall Rating	Discarded	Selected	Discarded

It is concluded from the above alternative study that the steel girder length of 82m is an optimum scheme from structural and economical aspects.

(4) Alternative Study of Connection Conditions

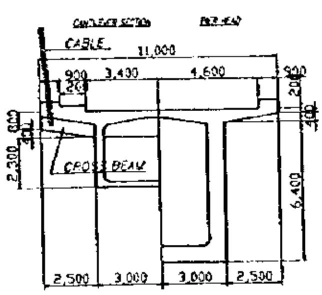
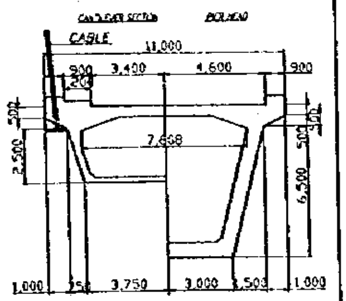
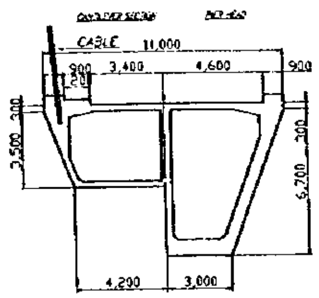
In extra-dosed bridges, there are several connection conditions of girder, pylon and pier depending on span arrangement, bridge width, height of pier. All the possible connection conditions are considered as alternatives in this study and the evaluation of each alternative is tabulated below:

	Alt-1	Alt-2	Alt-3
Connection Conditions	Pylon and Girder: Rigid Girder and Pier: Rigid Pylon and Pier: Rigid	Pylon and Girder: Free Girder and Pier: Free Pylon and Pier: Rigid	Pylon and Girder: Rigid Girder and Pier: Free Pylon and Pier: Free
Layout			
Structural Aspect	-Less fluctuation of stay cable stress due to live load -Bigger sectional force induced in pylon -High aseismicity due to high indeterminate structure -Indeterminate forces due to creep and shrinkage affects foundation	-Wider fluctuation of stay cable stress due to live load -Bigger sectional force induced in pylon -Effect to foundation due to seismic force of superstructure is intermediate between Alt-1 and Alt-3.	-Wider fluctuation of stay cable stress due to live load -Less sectional force induced in pylon -Less effect to foundation due to seismic force of superstructure.
Bearing & Maintenance	-No bearing required and Maintenance free	-Bearings and maintenance of the bearings are needed.	-A large scale of bearing is needed with periodical maintenance.
Similar Bridges in past	Odawara Blueway Bridge Tsukuhara Bridge Yashiro Bridge	Okuyama Bridge	Kanisawa Bridge Kiso/Ibi River Bridge Skikari Bridge

It is a fact from the structural analysis in Alt-1 that statically in determinate forces do not considerably affect the foundation because of flexibility of pile foundation applied. Hence, Alt-1 rigid connection between pylon, girder and pier is selected because of less construction cost and maintenance.

(5) Refinement of Main Girder Section

Considering the cross section of the bridge, several alternatives of the girder section were designed in order to select an optimum from structural, constructional, and economical aspects. The comparative study is shown in below:

	Alt-1	Alt-2	Alt-3
Section	Single Cell Box with Rectangular Section	Single Cell Box with Trapezoidal Section	Double Cell Box with Trapezoidal Section
Layout			
Structural Aspects	-Cantilever length from stay cable anchorage to web is long , which in turn induce sophisticated force transmission and need solid brackets -Total dead weight increase due to above brackets	-Smooth force transmission compared with other alternatives. -Not necessary any reinforcement for force transmission from stay cables -Total dead weight is less than others. -	-Deck slab span length is too short and not effective. -Stay cable and traveler crane intersect which in turn induces complicated erection. -Total dead weight is heavier than Alt-2.

From the structural advantage and less cost aspect, Alt-2:Single Cell Box with Trapezoidal Section is selected as an optimum.

(6) Study on Stay Cables

The stay cables in extra-dosed bridges consisting of overcoat pipes, injection materials and PC strands are functionally similar to external post-tensioning cables but are exposed to natural conditions such as rain and wind. Hence, anti-corrosion measure is requisite to prolong the cable life. Followings are comparative study of each component of the stay cables.

a) Overcoat Pipes

Polyethylene tubular pipes, steel tubular pipes and fibber reinforced polyethylene pipes are generally applied for overcoat pipes of the stay cables. Pros and cons of each material are as follows:

Evaluation Item	Alt.-1	Alt.-2	Alt.-3
Material	Polyethylene tubular pipes	Steel tubular pipes	Fibber reinforced polyethylene pipes
Cost	Cheapest	Intermediate	Expensive
Construction Aspect	Good	Bad	Good
Durability	Good	Poor, need anti corrosion protection	Good
Maintenance	Free	Periodical repainting is required.	Free
Records in past	Many	Several	Several

From the above comparison, Alt.-1 Polyethylene tubular pipes is selected as overcoat pipes.

b) Injection Materials

Cement grout and grease are generally applied for injection materials of the stay cables. Pros and cons of each material are as follows:

Evaluation Item	Alt.-1	Alt.-2
Material	Cement Grout	Grease
Cost	Cheaper	Expensive
Construction Aspect	Handling is the same as inner cables, Good	Job site handling is difficult, Bad
Durability	Good	Poor, leaking grease is possible in tropical countries.
Maintenance	Free	Periodical injection is required.
Records in past	Many	Several

From above comparison, Alt.-1 Cement Grout is selected as the injection material.

c) PC Strands

For the PC strands, there are two types of application, that is PC strands used without coating and with epoxy resin coating. However, past records indicates the majority is application of PC strands without coating. Hence, PC strands without coating is applied in this Study.

Consequently, the stay cables applied in this Study are composed of PC strands without coating enclosed by cement mortar and over-coated by polyethylene tubular pipes (PE pipes).

2.3 Basic Design

2.3.1 Design Concept

(1) Natural Conditions

1) Topography

The distance between the islands of Koror and Babeldaob in Toagel Channel is about 1.5km. The water depth from the surface to a coral reef, which extends between the two islands, varies from zero at the shore to about 2 to 3 meters near the channel slopes. The bridge construction site is located on reclaimed land in the coral reef. It is on the point of causeway, which runs out about 1 km from Koror Island into the sea. On Babeldaob Island side, the approach road of the old KB bridge is constructed on an embankment, which is filled on a 300m long reclaimed land in the coral reef.

From the coral reef edge toward the center of the channel, the channel depth gets deeper. The natural ground slopes are typically about 1 : 1 (horizontal to vertical) on the Koror side and about 1.2 : 1 on the Babeldaob side, down to the deepest point of about -20 m to -27 m. In the center of the channel, the slopes flatten considerably to become about -25m to -30m with the width of about 190m.

Under these topographic conditions, erection method of superstructure is balanced cantilever erection method for concrete bridges or blanket launching for steel bridges.

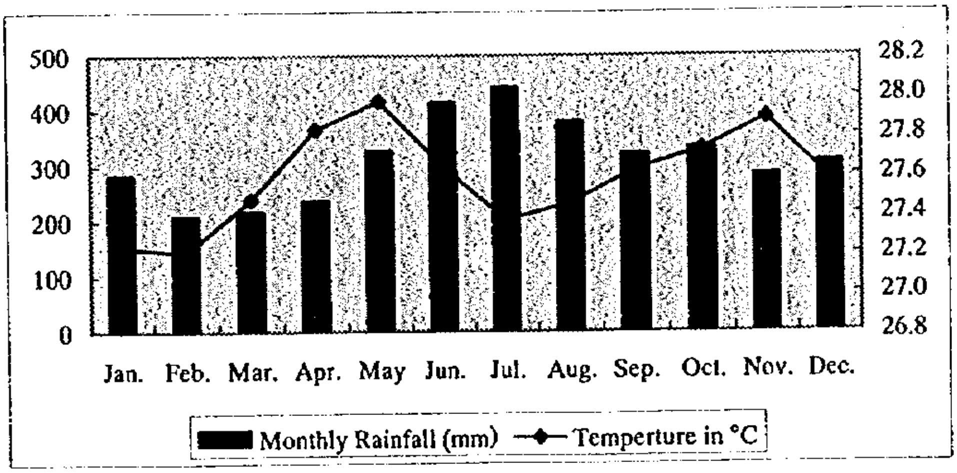
2) Geological Condition

Geologically, the area is overlaid by gravelly sand locally known as coral fragments with some layers of silty clay. Below these soil layers, andesite bedrock was encountered at elevations ranging from about –23 m to –29 m. andesite bedrock was also encountered at elevations varying approximately from -25m to -30 m at the channel.

Considering these geological conditions, pile foundation is appropriate with the bearing stratum of andesite. The ultimate pile tip resistance on andesite shall be evaluated thoroughly.

3) Meteorological Condition

Maritime tropical climate covers Palau. In Koror, the average daily high is 30°C and the average daily low is 24°C. Humidity averages 80% and the annual rainfall is 3,800mm. February and March are the driest months and June to August is the wettest period. Although Palau lies outside the main typhoon tracks, it occasionally gets hit. The fastest wind speed over the past 45 years is 32.6m/s.



As such, aerodynamic analysis is required for the superstructure and drainage design and pouring concrete schedule shall be paid special attention.

4) Oceanographic Condition

a) Design Wave Height

Based on wind records over the past 46 years, the probable offshore wave height with a return period of 50 years was estimated at 8.9 m with wave period of 11 seconds. The offshore waves are deformed by actions of shoaling and breaking on coral reef. The height of probable offshore wave of 8.9 m is, therefore, lowered to be 1.5 m of the design wave at the site after passing through the coral reefs. Considering workable condition of a barge, which is required during launching the girder, that is the design wave below 0.6m, a barge to be used in the project will be workable throughout the year except several days in the typhoon season since the return period of the wave height over 0.6m through a year is only 12 %.

b) Tidal Level

Based on tidal observation records at Malakal Port by the University of Hawaii and a real time tidal observation data at Malakal Port and the site, the various tidal levels to be applied in the Study were computed as follow:

Tidal Level	Abbreviation	Height of Tidal Gauge (cm)	Topo. Survey Elevation (cm)
Higher High Water Level	HHWL	226.69	59.09
Mean Higher High Water Springs	MHHWS	210.11	42.51
Bench Mark Zero	BM Zero	167.60	0.00
Mean Sea Level	MSL	137.34	-30.26
Mean Lower Low Water Spring	MLLWS	64.57	-103.03
Lower Low Water Level	LLWL	47.99	-119.61

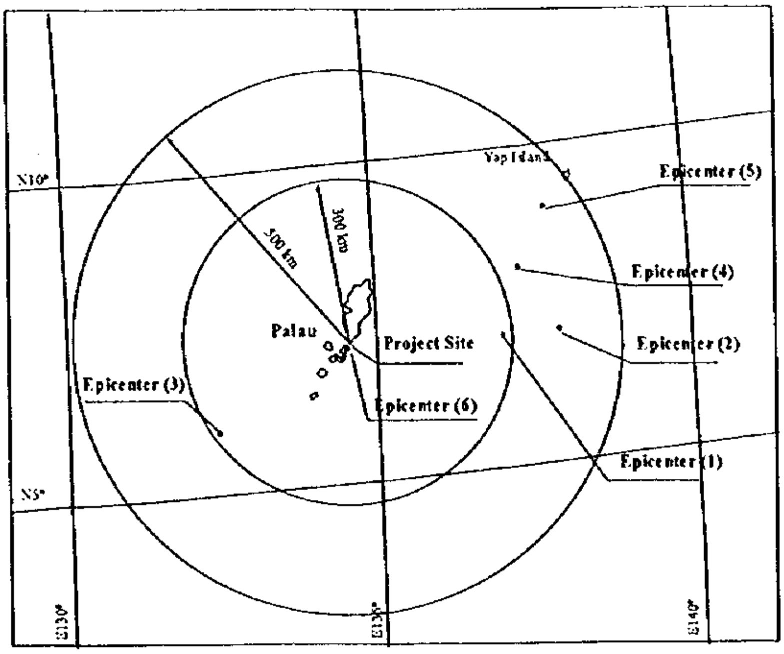
c) Tidal Current

Based on the correlation between current velocity and tidal range derived from survey results, the maximum tidal range per hour and maximum current velocity are estimated at 59 cm and 1.62m/s, respectively. The maximum current velocity measured was about 3m/s.

Considering workable condition of a barge below 2 knots and 33cm tidal range, a barge to be used in the project will be workable throughout the day except several hours in peak spring since the return period of the tidal range over 33 cm throughout a year is only 11 %.

5) Earthquake

Based on the historical data of earthquakes which occurred within a radius of 500 km from the project site and with more than Magnitude 4 since the year 1900 from the US Geological Survey Department, maximum lateral acceleration at the project site was computed using a formula specified in Japanese Bridge Design Specification at 86 gal which in turn gives a lateral seismic coefficient of 0.08. This result concludes that Palau is not situated in strong earthquake zone compared with that in Japan.



(2) Traffic Conditions

a) Vehicular Traffic

From the 24 hour vehicle traffic and pedestrian count survey done in the study, the net daily traffic volume and the number of pedestrian is about 4,300 vehicles and about 60 persons respectively. The peak hour is 7:00~8:00 in the morning and 17:00~18:00 in the afternoon. The most dominant vehicle type is 4WD amounting to 58% of the total. Accordingly, a bridge with two lanes, which is the same as the existing, is sufficient for a new KB bridge.

b) Sea Traffic

The data of the vessels which will pass through the KB channel after the new bridge is completed are summarized as follows:

Name of Vessel	Type	Owner	Gross Ton	Net Ton	Length In Meter	Mast Height In meter/1
KB Queen	Ferry Boat	Government of Palau	97.77	50.05	28.7	11.7
M/V Sekang	Passenger Boat	Angaur State	80.42	55.91	N/A	9.4
Vincennes II	Fishing Vessel	Hatobei State	49.2	N/A	21.21	13.8
ASL Bintang	Tag Boat	Surangel	81.89	7.86	21.04	
H.I. Remeliik	Patrol Boat	Government of Palau	N/A	165	31.5	17.0

Note:/1means height from sea level to top of mast

From this table, it can be concluded that the navigation height of the new KB bridge should be not less than 17.0 m taking into account the mast height of 17.0m of H.I. Remeliik and the width is 70 m which is about two times the vessel length. It is noted that the navigation clearance of the old KB bridge was 55ft(16.7m).

(3) Circumstances of Construction Conditions

The existing public utilities and facilities have to be used as much as possible to reduce and save on construction costs. Electricity, water, and telephone services are presently available at the project site for this bridge construction purpose. Malakal port is available to be used for handling of small and light weight goods of the Project.

Skilled and semi-skilled workers are not available in Palau for the bridge construction works. It is necessary to employ these types of workers from neighboring countries such as Philippines, Indonesia, and Japan.

Most of the construction plant and equipment are not available in Palau and have to be imported from abroad. However, small types of construction equipment for road and other minor works are planned to be leased or rented from the contractors in Palau.

A temporary facility yard must be constructed for the base camp, concrete mixing plant, material stock and others. Proposed yards are a corner of Ngetmeduch Island, beside the bridge site at Airai side, and beside the school compound of Airai Elementary School. To construct temporary yards on the sea side, concrete fragments resulting from demolition of the old KB bridge shall be used.

(4) Applicability of Local Contractors and Materials

At present, about thirty (30) firms are operating in the construction field in Palau. Among these, only six (6) civil contractors have standard and small class of construction equipment and a few staff members. Most of them are building contractors and are of a relatively small scale. They are only expected to be involved in the project for minor works.

The major construction materials required for this bridge works are 1) cement, 2) reinforced steel bars, 3) concrete aggregates, 3) temporary supports and staging materials, 4) structural steels, 5) PC bars and cables, 6) asphalt, and 7) fuel and lubricants. Fuel and lubricants are available in Palau, however, the other materials are either not available in Palau or technically not sound, so that have to be imported from abroad. The fine and coarse aggregates produced in Palau are used only for lower grade of concrete. A lot of fine and coarse aggregates are imported either from Taiwan, Philippines, Malaysia or Singapore to meet the technical requirements. To import concrete aggregates, a chartered barge is planned to be used from an economical point of view.

(5) Capability of Executing Agency for Maintenance and Operation Works

The Ministry of Resources and Development (MRD) is responsible for operation and maintenance of the infrastructures including the roads and bridges in Palau, and is the counterpart agency for the Study and the project implementation. It seems obvious that MRD faces shortage of funds for the construction and maintenance of roads and bridges, and has not enough experienced local engineers.

It is important to design the new KB bridge with free maintenance and without sophisticated and high level technique maintenance, and enhance local engineer's technical and managerial capability through on the job-training during the project implementation.

(6) Construction Schedule

The construction schedule is formulated taking into account the following factors:

- Rainfall pattern (dry and rainy seasons) at the job site,
- Period required for the materials and equipment procurement from the third countries and Japan,
- Custom clearance situation at Malakal Port,
- Possible field works and appropriate construction method during rainy season,
- Safety measures, and

The construction works are divided into three (3) fiscal years as summarized below:

The first year

- Mobilization
- Installation of cofferdams
- Construction of foundation of piers 1 and 2

The second year

- Construction of pile caps and pier shafts of piers 1 and 2
- Construction of foundation and abutments of abutments 1 and 2
- Construction of side spans (Koror and Airai sides)
- Construction of pier heads
- Construction of pylons
- Construction of center spans
- Fabrication of steel girder

The third year

- Construction of center spans (continuation)
- Fabrication of steel girder(continuation)
- Erection of steel girder
- Field painting
- Deck slab work
- Bridge surface pavement
- Installation of incidental facilities
- Construction of approach roads
- Demobilization

2.3.2 Basic Design

(1) Overall Scheme

The whole scheme of the project designed based on the basic concepts applied in the Study is outlined as follows:

Bridge Location	The center line of the new bridge is located the same as the existing.
Total Project Length	442.3m
Total Bridge Length	412.3m
Bridge Type	3 span continuous hybrid extra dosed bridge
Span Length	82m+247m+82m
Bridge Width	Dual lane with 4m carriage way and 1.2m of sidewalk
Pylon	H shape RC structure with a height of 40.684m
Foundation of Pylon(Koror side)	Cast in place RC pile by all casing method with dia. 2.0m and 25.5m long
Foundation of Pylon(Airai side)	Cast in place RC pile by all casing method with dia. 2.0m and 30m long
Abutment (Koror side)	Bank seat abutment (7m height) on single row cast in place RC pile by all casing method with dia. 2.0m and 30 m long
Abutment (Airai side)	Bank seat abutment (7m height) on single row cast in place RC pile by all casing method with dia. 2.0m and 36.5 m long
Approach Road Length	15m (Koror side) 15m (Airai side)
Road way Width	Nos of lane-2,Lane width 3.00m (10'-0") Shoulder width 0.60m(2'-0") at sidewalk side Shoulder width 1.20m(4'-0") at fill side Sidewalk 1.20m (4'-0") at one side

(2) Design Conditions

1) Geometric Criteria

Referring to A Policy on Geometric Design of Highways and Streets 1994 by AASHTO, the following are applicable geometric criteria in the study.

Elements	:Applicable Criteria
Road Classification	:Local Road per AASHTO
Design Speed	:50 km/h (30mph)
Max. Gradient	:6%
Cross Fall	:2%
Min. Vertical Curve Length	:110m

2) Bridge Design Criteria

Elements	Applicable Criteria
Live Load	:HS 20-44 in AASHTO ,which is about 7% less than that due to TL-20 in the Japanese Design Specification
Wind Load	:55 m/sec (125 MPH)of design wind speed in accordance with US Building Code.
Earthquake Load	: 0.1 of horizontal seismic coefficient is applied based on following reasons; -Horizontal seismic coefficient of the old bridge applied is 0.1. -The US building Code stipulates 0.1 in Palau. -The historical earthquake records indicates 0.05.
Thermal Effect	:Standard temperature 28°C、 ±10°C

3) Ultimate Pile Tip Resistance

Based on comparison of the ultimate pile resistances estimated by three different methods as tabulated below, the ultimate pile tip resistance applied in study was determined as 1500ton/m2.

Method	Estimated Ultimate Pile Resistance
Load Test Results of Old Bridge Foundation	2,000 ton/m2
Unconfined Compression Test of Andesite taken from Boring	1,800 ton/m2
AASHTO	1,500 ton/m2

4) Allowable Pile Head Displacement

The allowable pile head displacement is 1% of the pile diameter which is equivalent to 20mm in accordance with Standard Specification of Roadway Bridge in Japan.

5) Unit Weight of Materials

Material	Unit Weight
Steel	: 77 kN/m^3 (7,850 kg/m^3)
Prestressed /Reinforced Concrete	: 25 kN/m^3 (2,500 kg/m^3)
Plain Concrete	: 21 kN/m^3 (2,150 kg/m^3)
Asphalt Concrete	: 22 kN/m^3 (2,300 kg/m^3)

6) Material Strength

- Superstructure

Material	Specification	Min. Strength	Min. Yield Point
PS Concrete	Main Girder	40 Mpa (Compression)	N/A
Plain Concrete	Counter weight	18 Mpa (Compression)	N/A
Strand	S15.2(SWPR7B)	261kN (Tensile)	222 kN
PC Bar	SBPR 930/1180	1100N/mm2(Tensile)	950 N/mm2
Rebar	SD295	440 N/mm^2(Tensile)	295~390 N/mm^2
	SD345	490 N/mm^2(Tensile)	345~440 N/mm^2
Structural Steel	SS400(t < 16 mm)	400 ~ 510 N/mm^2(Tensile)	245 N/mm^2
	SS400(16< t < 40mm)	400 ~ 510 N/mm^2(Tensile)	235 N/mm^2
	SM490Y(t < 16 mm)	490 ~ 610 N/mm^2(Tensile)	365 N/mm^2
	SM490Y(16< t < 40mm)	490 ~ 610 N/mm^2(Tensile)	355 N/mm^2
	SM520(t < 16mm)	520 ~ 640 N/mm^2(Tensile)	365 N/mm^2
	SM520(16< t <40 mm)	520 ~ 640 N/mm^2(Tensile)	355 N/mm^2

- Substructure

Material	Specification	Min. Strength	Min. Yield Point
Concrete	Pylon	40 Mpa (Compression)	N/A
Concrete	Pile Cap	24 Mpa (Compression)	N/A
Concrete	Pile	30 Mpa (Compression)	N/A
Rebar	SD295	440 N/mm^2(Tensile)	295~390 N/mm^2
	SD345	490 N/mm^2(Tensile)	345~440 N/mm^2

(3) Contents of Basic Design

The concept of " extra-dosed " bridges , where stay cables are functionally similar to external post-tensioning cables, was introduced by Jacques Mathivet in 1988. After introduction of this technique, several prestressed concrete extra-dosed bridges had been constructed, especially in Japan. A new KB bridge which is hybrid extra-dosed type bridge is the second application in the world after Kiso River and Ibi River Bridge in Japan.

Based on the whole scheme formulated and the design conditions applicable to the study, the basic design of the superstructure, substructure, approach roads, shore protection and incidental facilities was done and the design results are as follows:

1) Main Girder (PC Girder, Steel Girder, Joint Section and Pavement)

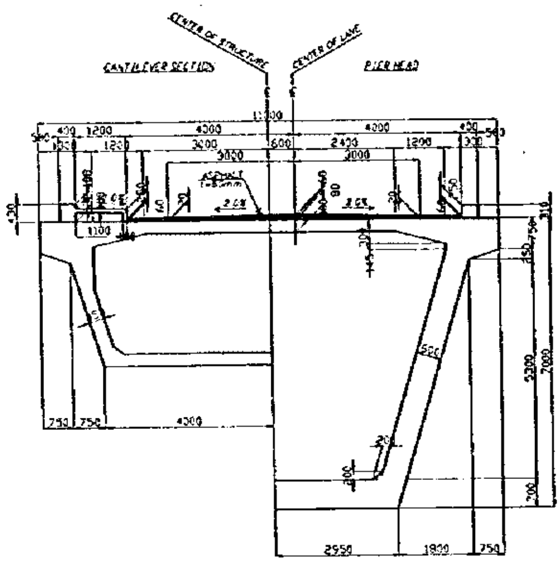
It has been reported that application of higher pylons with live load stress fluctuation less than allowable induces slender girders, under which the bridge cost is in turn economical. Considering this concept, the girder is designed as economical as possible.

Because of the hybrid type, there are two sorts of the girder, Prestressed Concrete Girder (PC girder) and Steel Girder.

a) PC Girder

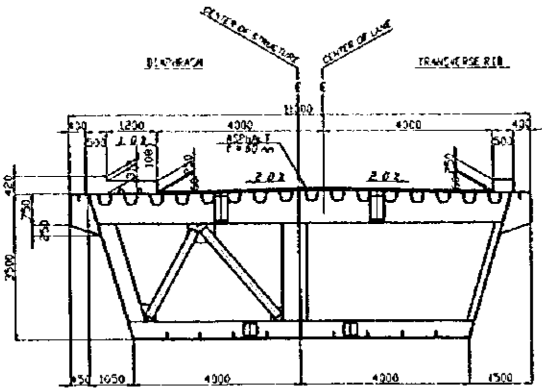
The girder is designed with single cell box girders instead of the conventional two cell girders in order to reduce the dead weight of the girder, resulting in a slab span of 7m. Application of the large blocks varies from 3.5m to 5.0m in length is also introduced to enhance efficiency of erection using a large size travelling form.

The internal tendons, which are placed inside the girder to resist bending moments and used for cantilevering, are mainly 12 strands 15.2 mm (SWPR7B) diameter and 4 strands 15.2 mm (SWPR7B) diameter in transverse in the deck slab.



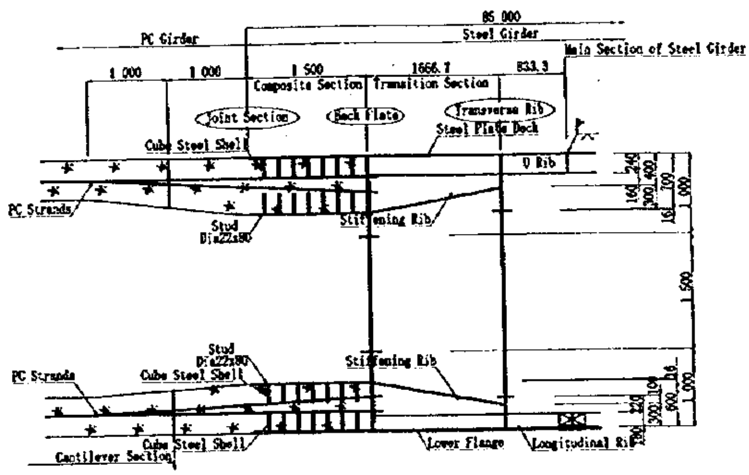
b) Steel Girder

The steel box girder is designed with the same trapezoidal section as the PC section and is a double cell of one box with steel plate deck stiffened by U shape ribs. The steel girder is launched on a blanket erection method by using the erection noses after ocean transport of the fabricated girder using a barge with capacity of 7,000 ~ 5,000 ton from the third world country or Japan where the steel girder is fabricated.



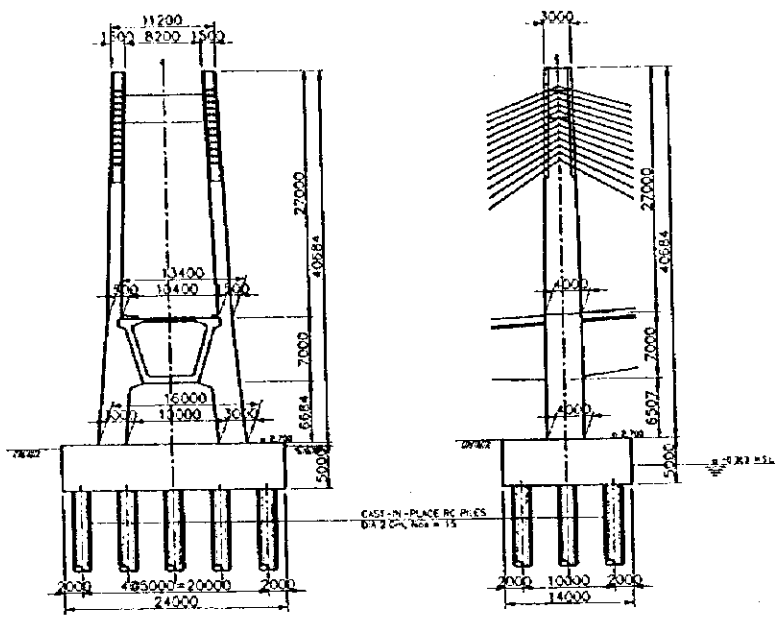
c) Joint Section

The joint section is designed referring to satisfactory results in Iguchi bridge, Tatara bridge and Sun marine bridge which are all cable stayed bridges in Japan and Kiso and Ibi bridges which are hybrid type extra-dosed bridges in Japan. The joint type is so called as back side plate method without solid concrete diaphragm as illustrated below:



2) Pylons

Piers and pylons are H-shaped and stay cable forces flow top to bottom. Cross beams between the pylons are necessary to resist torsional moment due to hound's tooth arrangement of the stay cables. Saddles are not used at the top of the pylons because of tension force difference caused by the unbalanced span arrangement.



3) Stay Cables

The stay cables of a new KB bridge form a replaceable external cable system. Each stay cable consists of 37~12 strands 15.2 mm in diameter, protected against corrosion with non-bleeding cement grout and polyethylene tubular pipe. As the maximum stress fluctuation in the stay cables due to live load is 7.6 kgf/mm2, 0.45fpu (fpu is the strength of the stay cables) is adopted as an allowable stress of the stay cables. Therefore, there is no need for special anchorages with high fatigue strength, such as those used in cable stayed bridge.

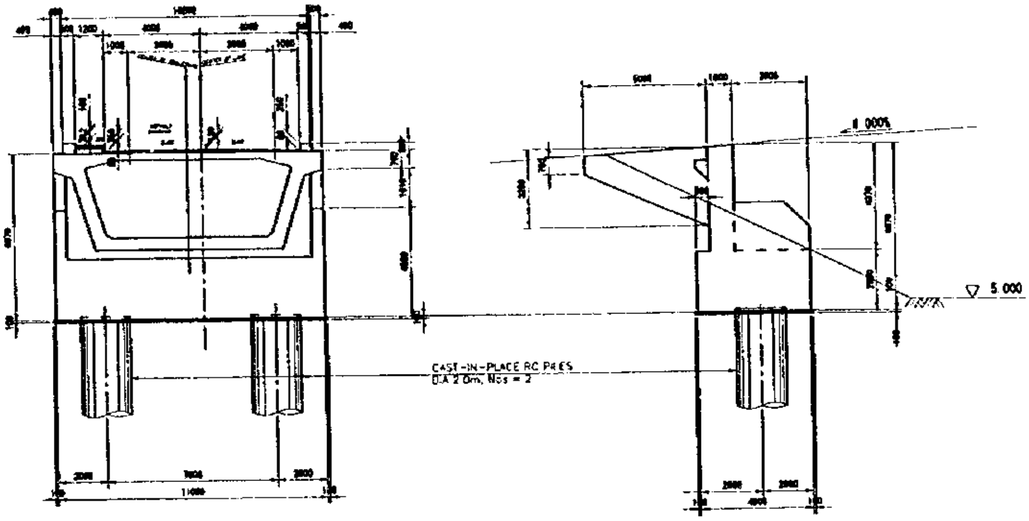
4) Substructures

a) Piers and Foundation

Considering the design conditions of allowable pile head displacement and ultimate pile tip resistance, the foundation of the piers is designed. The pile arrangement is 5 rows and 3 columns totaling 15 piles required with actual pile head displacement of 18.4 mm. The pile cap is rectangle 24 m in transverse and 14 m in longitudinal.

b) Abutment and Foundation

Bank seat type abutment rested on single row pile is selected from economical aspect. The connection condition with superstructure is movable and 2 piles in columns are required with pile head displacement of 18 mm which is less than the allowable 20 mm.



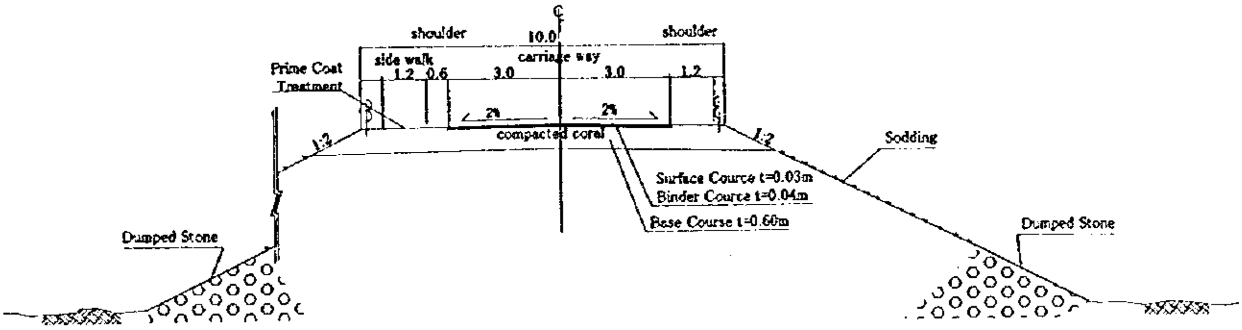
5) Shore Protection

Watertight cofferdams or cribs using steel sheet piles are installed to de-water the foundation before construction of the foundation piles and pile cap. After the construction is completed of these structures, the cofferdams remain and are used as shore protection after placing seal concrete between the pile caps and the sheet piles.

6) Approach Roads

Most of the existing approach roads at present are re-used as approach roads of the new KB bridge except where the section is affected by construction of the abutments. This section which is defined as an approach road in the study is reconstructed and the length is 15 m from the back wall of the abutment to beginning or ending point of the project. The pavement composition applied in the Study is the same as the existing consisting of compacted coral 60 cm thick and asphalt pavement 7 cm thick in total.

Typical Crosssection



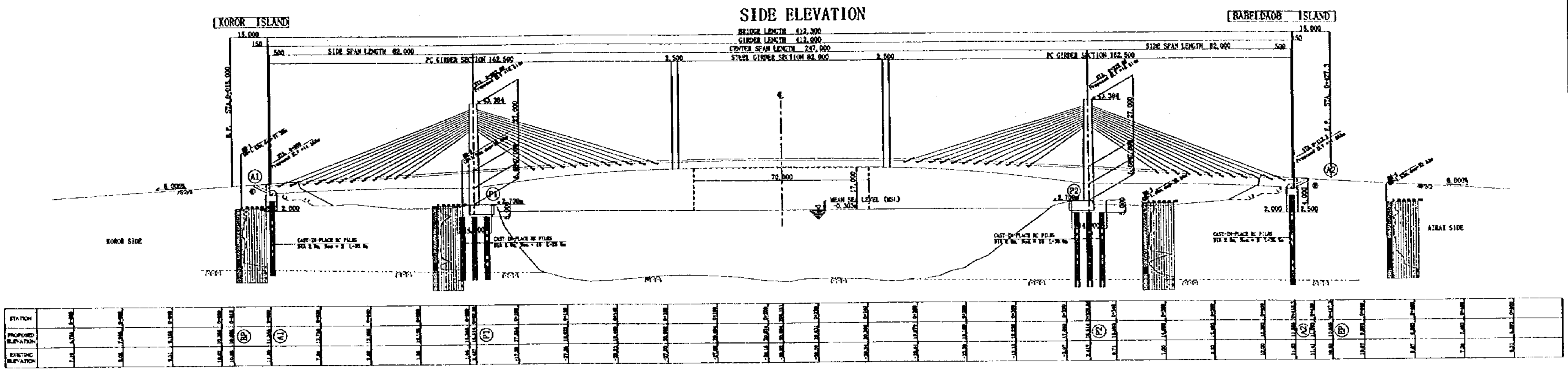
7) Incidental Facilities

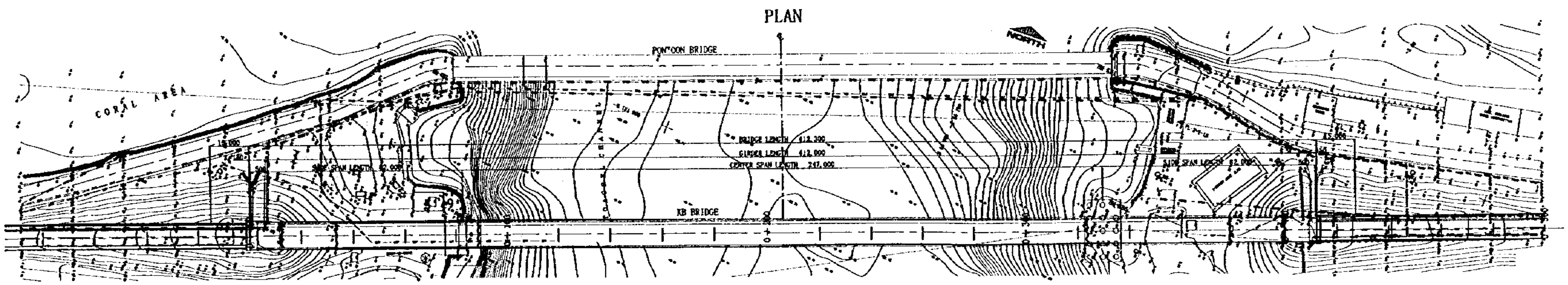
The incidental facilities incorporated into the Study are as follows:

Item	Type
Drainage Facilities	Catch basins by cast iron with PVC vertical pipes
Expansion Joints	Finger joint by structural steel
Bridge Railings	Zinc coated steel railing
Approach slabs	Reinforced concrete
Bearing s	Elastomeric bearing pads
Entering Protection Fences	Galvanized wire mesh fence with 2 m height
Lighting Facilities	Street lighting pole with fluorescent mercury lamp
Navigational Lights	
Lightning Rods	
Newel Posts	Concrete with stone plate
Guard Rails	Beam type guard rail
Bridge Plates	600mm*300mm plate by cast iron
Traffic Sign Boards	Speed and Load limit sign boards

(4) Drawings

The basic design drawings are attached in the following pages.





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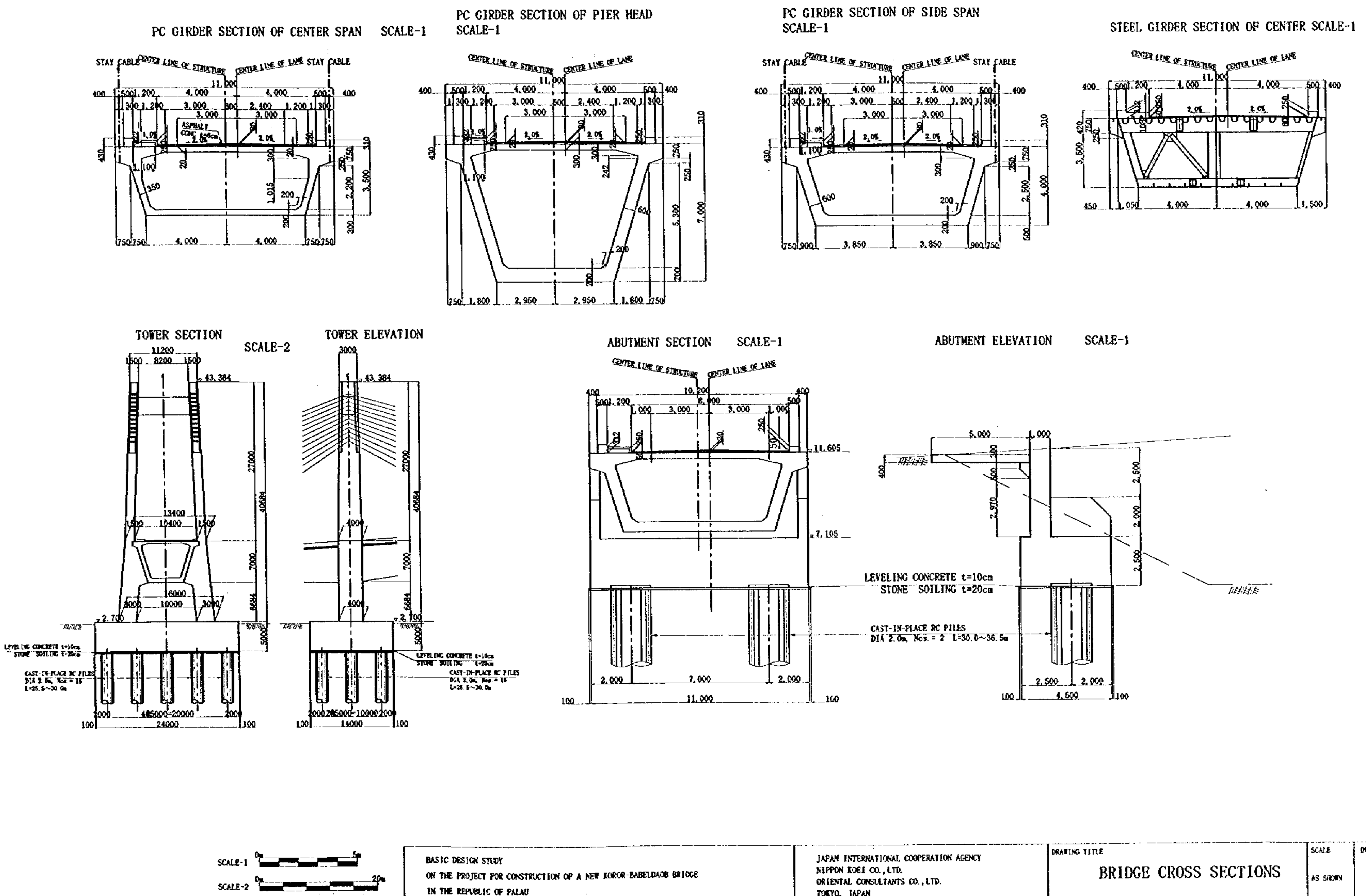
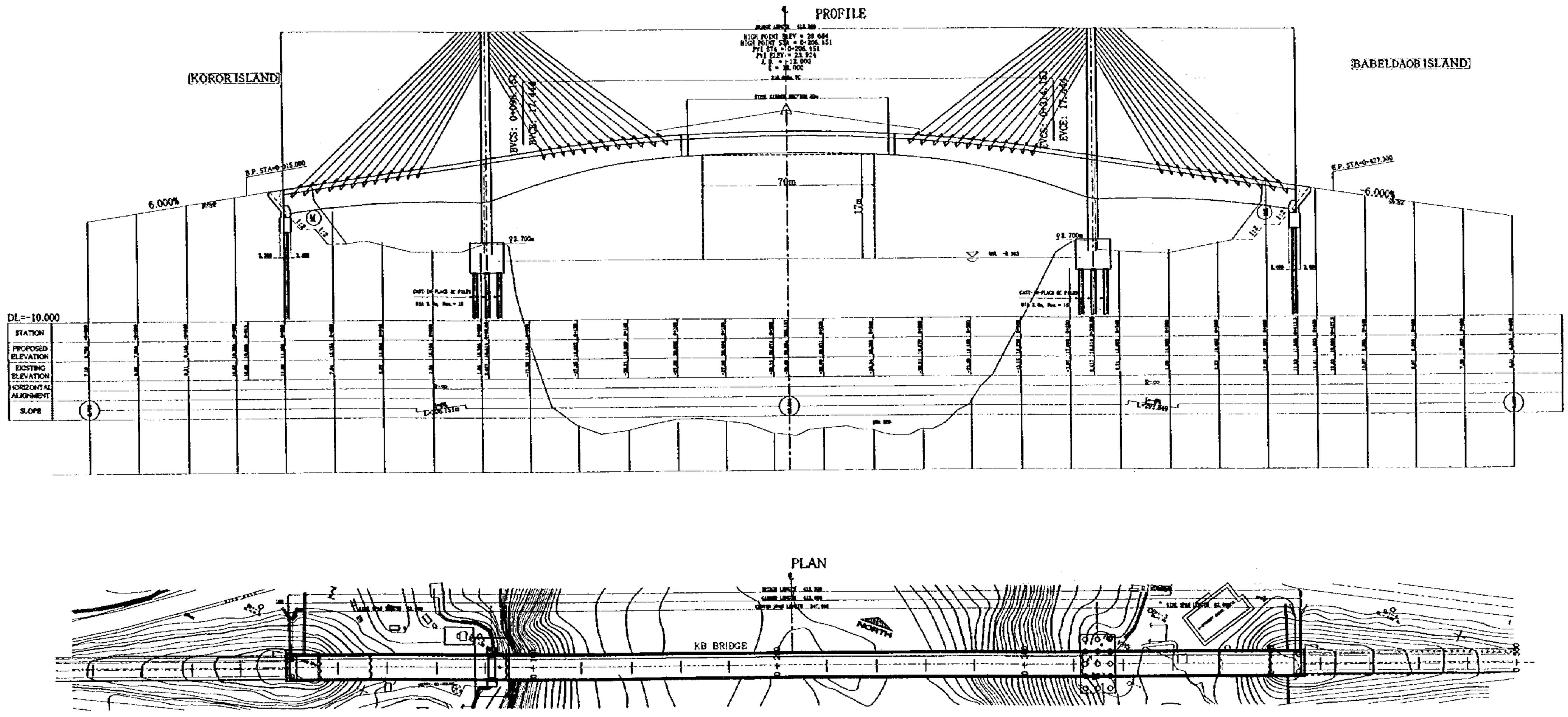
BASIC DESIGN STUDY ON THE PROJECT FOR CONSTRUCTION OF A NEW KOROR-BABELDAOB BRIDGE IN THE REPUBLIC OF PALAU	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. ORIENTAL CONSULTANTS CO., LTD. TOKYO, JAPAN	DRAWING TITLE GENERAL VIEW	SCALE AS SHOWN	DRG.No. 1



BASIC DESIGN STUDY ON THE PROJECT FOR CONSTRUCTION OF A NEW KOROR-BABELDAOB BRIDGE IN THE REPUBLIC OF PALAU	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. ORIENTAL CONSULTANTS CO., LTD. TOKYO, JAPAN	DRAWING TITLE BRIDGE CROSS SECTIONS	SCALE AS SHOWN	DWG No. 2

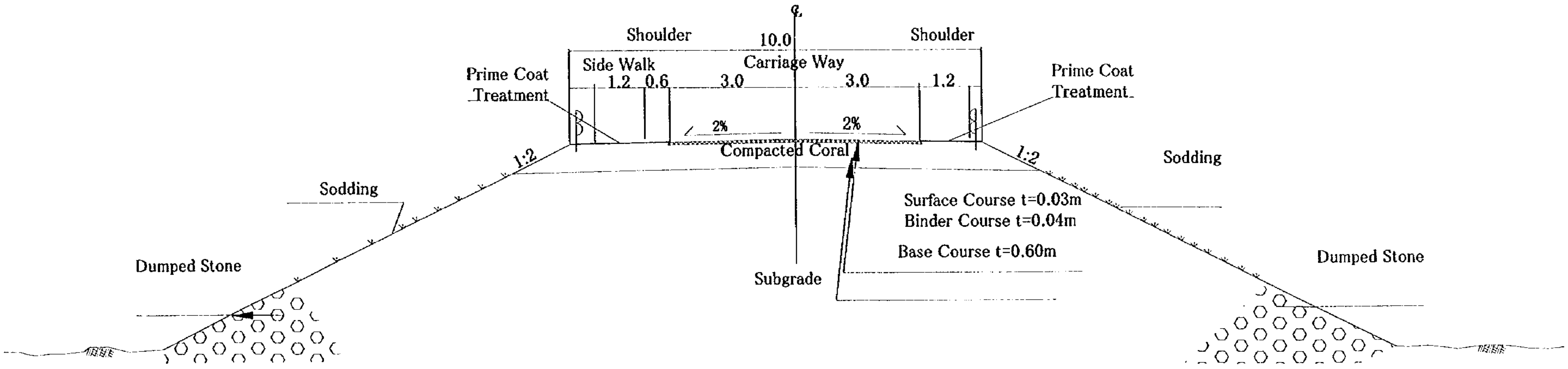


SCALE : V 0m — 20m

SCALE : H 0m — 50m

BASIC DESIGN STUDY ON THE PROJECT FOR CONSTRUCTION OF A NEW KOROR-BABELDAOB BRIDGE IN THE REPUBLIC OF PALAU	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO.,LTD. ORIENTAL CONSULTANTS CO.,LTD. TOKYO, JAPAN	DRAWING TITLE PLAN AND PROFILE	SCALE AS SHOWN	DWG.No. 3

TYPICAL CROSS-SECTION



SCALE 0m 3m

BASIC DESIGN STUDY ON THE PROJECT FOR CONSTRUCTION OF A NEW KOROR-BABELDAOB BRIDGE IN THE REPUBLIC OF PALAU	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO.,LTD. ORIENTAL CONSULTANTS CO.,LTD. TOKYO, JAPAN	DRAWING TITLE ROAD CROSS SECTION	SCALE AS SHOWN	DWG No. 4