CHAPTER 8 CASE STUDY OF FLOOD MITIGATION BY AFFORESTATION / REFORESTATION

8.1 Case Study Area

The Sigatoka watershed was selected for the case study of flood mitigation by afforestation/reforestation, with the following reasons;

- The most part of the Sigatoka watershed is located in "dry zone", and the forest cover is less than 50 % of the watershed area (Supporting Report Part II, "Forest and Soil Erosion").
- The difference between the design flood discharge (1/20 probability) and the current flow capacity in the Rewa, Nadi and Ba watershed is so large that non-structural measures can not deal with it. However, the difference in the Sigatoka watershed is as low as 300 m^3/sec that could be solved by non-structural measures.
- As the native villages are distributed along Sigatoka river and Sigatoka town extends up to the river bank, land acquisition for structural measures would be difficult and only river bed excavation (dredging) could be considered as a structural measure, which is not a permanent countermeasure. Therefore, the non-structural measure (afforestation) should be examined as a possible countermeasure.

The afforestation area in the Sigatoka watershed is planned to be 233 km^2. Priority shall be placed on the area around the divide of the Sigatoka-Ba watersheds where urgent countermeasures for soil erosion are required as the decrease of forest has been remarkable recently and the annual rainfall is large.

The discharge to be reduced by afforestation is 300 m^3/sec which is the difference between the design flood discharge (1/20 probability) and the current flow capacity.

8.2 Flood Mitigation Effect of Afforestation

The runoff model to assess the effect of afforestation quantitatively was made based on the storage function method used for the runoff analysis in this Study. Effects of forest on flood mitigation are;

a) To reduce a part of flood discharge temporarily and drain it as normal runoff after flood

b) To increase the water retention capacity of watershed

The storage function method was formulated considering retention phenomenon during the runoff and its dynamic equation is as follows.

$$S_l = kQ_l^p$$

where

S_l : storage of water in watershed or river channel

Q_l : runoff

k, p : constant

In the runoff model for afforestation, the effect of a) is accounted as the runoff coefficient, *f*. As the runoff coefficient is reduced, the flood discharge decreases accordingly. According to Kadoya (1988), the difference of the average peak runoff coefficient between woodland (0.4) and grazing area (0.5) is 0.1 as shown in Table-E8.1. Therefore, the effect of afforestation on flood discharge was considered by reducing *f* by 0.1. Since *f* for the runoff analysis is assumed 0.5 over the whole watershed, *f* for afforestation was assumed 0.4.

Table-E8.1 Peak Runoff Coefficient by Land Use

Land Use	Peak Runoff Coefficient (*f*)	Average
Woodland	0.35 ~ 0.45	0.40
Grazing Area	0.4 ~ 0.6	0.50
Golf Links	0.45 ~ 0.6	0.53
Playground	0.8 ~ 0.9	0.85
Urban	0.8 ~ 1.0	0.90

Source: Kadoya (1988)

Meanwhile in order to evaluate the effect of b), the kinematic wave method was employed which is another method explaining the runoff phenomenon of rain. This method was formulated on condition that the runoff phenomenon of rain was assumed as the flow on slope and river course, and its dynamic equation is as follows.

$$h = k'q^p$$

where

h : depth of water

q : runoff

k', p : constant, $k' = \left(\frac{N}{\sqrt{S}}\right)^{0.6}$

N : equivalent to roughness coefficient

S : slope

Table-E8.2 Standard Value of N

Land Use	N	Average
Woodland	0.6 ~1.2	0.9
Grazing Area, Golf Links, Cultivation Area	0.3 ~0.5	0.4

Source: Hathaway (1944), Palmer (1946)

The equation of the storage function method resembles that of the kinematic wave method and there is similarity in the constants of both methods. In the kinematic wave method, the influence of land use to the runoff is accounted the equivalent coefficient of roughness *N*. According to Hathway (1994) and Palmer (1946), the average equivalent coefficient of roughness *N* for woodland is approximately twice as big as one for grazing area, golf links and cultivation area. Applying this difference, it was assumed that the equivalent coefficient of roughness *N* for grassland and grazing area would be twice as big as the current value after the implementation of afforestation. When *N* is double, *k'* will be $2^{0.6}$ times larger. Since the constant *k* in the storage function method is assumed to change in proportion to the constant k' in the kinematic wave method, k also will be $2^{0.6}$ times larger to take account of the water retention capacity of watershed.

The result of the runoff model application for afforestation is shown in Table-E8.3. If the total forest area of 952 km^2 was achieved by afforestation of 233 km^2 in the Sigatoka watershed, the flood discharge of 270 m^3/sec would be reduced by the effect of the forest. Since 270 m^3/sec is almost same as the difference (300 m^3/sec) between the design flood discharge and present flow capacity, afforestation in the Sigatoka is possible to replace the structural measures.

Table-E8.3 Effect of Afforestation in Sigatoka Watershed

Sigatoka Watershed	Flood Discharge (m^3/sec)	Total Discharge (1,000 m^3)
Present Condition	2,900	80,049
After Afforestation	2,630	73,948
Effect by Afforestation	-270	–

Note: Design flood is 20 year return period flood in accordance with the runoff analysis (Chapter 6).

8.3 Evaluation

Relation between flood damage and discharge in the Sigatoka watershed was determined as shown in Figure-E8.1. Based on that relation, annual average damage reduction by afforestation was estimated and the result is shown in Table-E8.4. The benefit of the afforestation is equivalent to the annual average damage reduction, F$ 186,000/year.

Economic evaluation was conducted to assess feasibility of afforestation in the Sigatoka watershed assuming that the project life is 100 years. As a result, EIRR is negative and B/C is equal to 0.1 as discussed in Chapter 4. The benefit here was estimated only in terms of flood damage reduction. However, the benefit from forests should include various aspects, such as prevention of soil erosion, mitigation of sedimentation, conservation of water resources, protection of river turbidity, conservation of diversified animals, plants and coral reef or eco-system, contribution to tourism etc. whose quantitative estimate is difficult. Taking into account the total benefit of afforestation, it would be safely said that the afforestation should be feasible.

Table-E8.4 Estimate of Annual Average Damage Reduction (Sigatoka)

River	Return Period		Annual Average Return Periods	Discharge: Current	Discharge: After Imple-mentation	Discharge: Effect	Flood Damage: Current	Flood Damage: After Imple-mentation	Flood Damage Reduction	Average Flood Damage Reduction	Annual Average Flood Damage Reduction
			①	②	③	④=②-③	⑤	⑥	⑦=⑤-⑥	⑧=(⑦n+⑦n-1)/2	⑨=①x⑧
				m^3/sec	m^3/sec	m^3/sec	10^{3}F$	10^{3}F$	10^{3}F$	10^{3}F$	10^{3}F$
Sigatoka	1/20	0.050	-	2,900	2,630	270	9,314	7,733	1,582	-	-
	1/10	0.100	0.050	2,200	2,000	200	5,214	4,042	1,172	1,377	69
	1/6	0.167	0.067	1,650	1,500	150	1,992	1,113	879	1,025	68
	1/5	0.200	0.033	1,460	1,320	140	879	59	820	849	28
	1/4	0.250	0.050	1,310	1,190	120	0	0	0	410	21
Total											186

Damage by Cyclone KINA

Watershed	Sigatoka	Remark	
(1)General Assets	4,710,000	Effective Ratio of Measures	0.718
(2)Agricultural Crops	6,160,000		
(3)Business Activities	75,000		
(4)Public Structure	1,884,000	(1) x 40%	
Total	12,829,000		

12,829 10^3 F$

Sigatoka River

Whole Catchment Area(km²)		1,450
Harmless Discharge	Point (km)	3.0
	Catchment Area (km²)	1,439
	Ground Height (EL m)	2.40
	Clearance (m)	0.00
	Water Level (EL m)	2.40
	Q (m³/s)	1,300
	Q at River Mouth (m³/s)	1,310 1/4*
Discharge of Cyclone KINA (1/30)		3,500

Damage(10^3 F$)	Q(m³/s)
0	1,310
12,829	3,500

*: Return Period of Harmless Discharge

Q: Discharge

Point: Distance from River Mouth

Q=aD+b : a= 0.171 b= 1,310

D=cQ+d : c= 5.858 d= -7,674

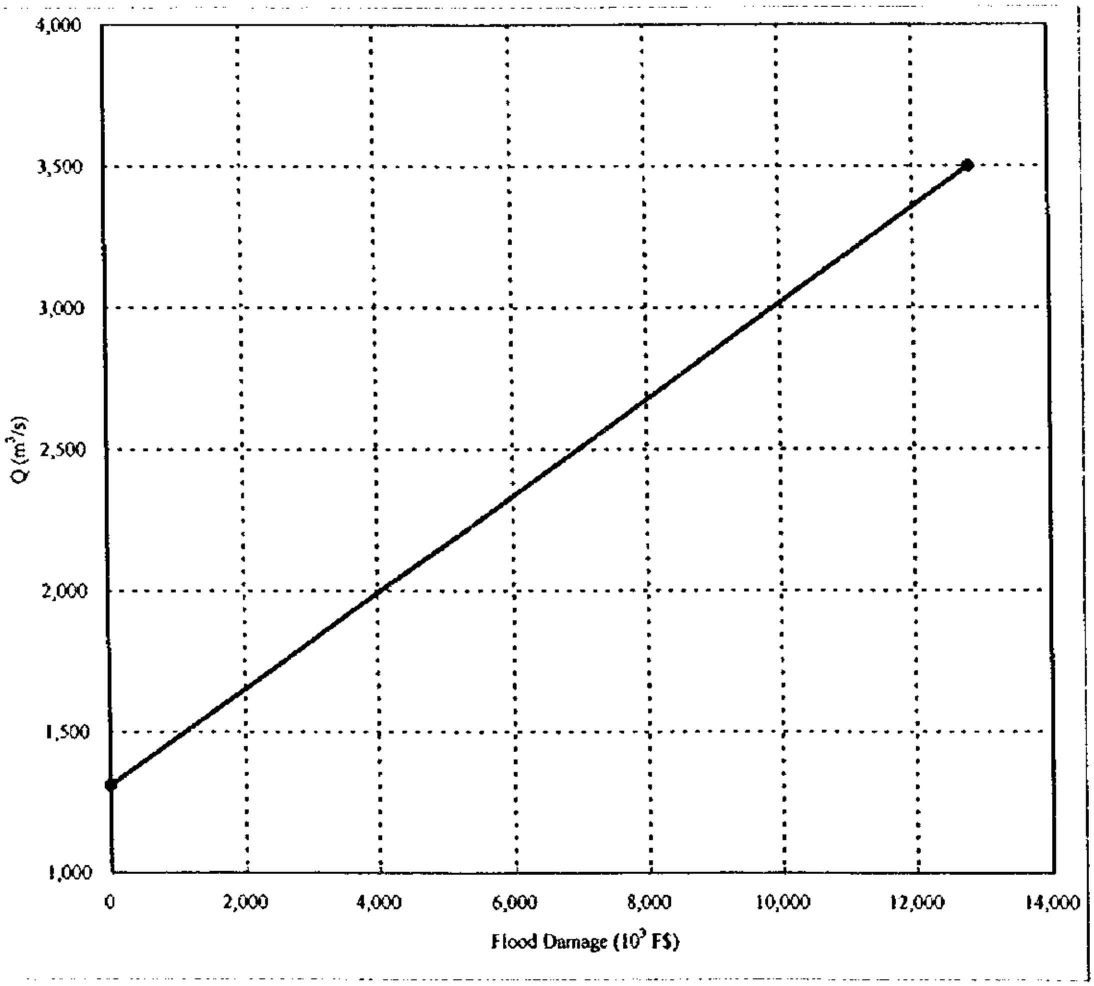


Figure-E8.1 Relation between Flood Damage and Discharge (Sigatoka)

Literature Cited

Hathaway G. A., (1944). "Design of Drainage Facilities.", Military Airfield, A Symposium, *Proc* ASCE, Vol. 70, pp.55-89.

M. Kadoya (1988). "Changes in runoff characteristics due to those in land use.", Journal of the Japanese Society of Irrigation, Drainage and Reclamation Engineering, Vol. 56, No. 11, pp.1061-1065.

Palmer V. J. (1946). "Retardance Coefficients for Low Flow in Channels Lined with Vegetation." *Trans.* AGU, Vol. 27, pp.187-197.

CHAPTER 9 POTENTIAL FLOOD CONTROL MEASURES AND PRIORITY PROJECT FOR FEASIBILITY STUDY

9.1 Potential Flood Control Measures

The flood control plans were examined and formulated for 20 year return period flood. Considering the current flow capacity and assets located in the flood prone areas, the flood damage would be reduced enormously by implementation of structural measures and non structural measures proposed.

However, the characteristics of the target 4 watersheds require a flood control plan for 50 year return period flood. As the development expands and population increases in future, the potential of flood damage will be high resulting in the necessity to formulate the flood control plan for 50 year return period flood. As shown in Figure-E4.1, there are still applicable structural measures. Based on those measures and methodologies adopted by the Study Team, the flood control plan for 50 year return period should be examined and formulated when required.

9.2 Project for Feasibility Study

A priority project for the Feasibility Study was selected from flood control master plans proposed because of their drastic effects on flood damage mitigation. For the selection, the following factors were considered (see Chapter 10 in Main Report).

1) Present Capacity of River Channel
2) Population in Beneficial Areas
3) Total Project Cost
4) Average Annual Damage Reduction
5) Economic Effect
6) Land Acquisition and Compensation
7) Impact on Social and Natural Environment

As a result, the flood control measures in the Nadi watershed, which consist of diversion channel and short cut channel, were found suitable for the priority project.

At the beginning of the Feasibility Study, November 14th 1997, the selection of the priority project was discussed in the Steering Committee, and the Nadi diversion channel and short cut channel were finally determined as the priority project by mutual consent of MAFF, the Steering Committee and the Study Team. The Feasibility Study on the priority project was commenced from November, 1997.

The results of the Feasibility Study are discussed in the following chapters.

CHAPTER 10 EXAMINATION OF SCALE OF DIVERSION CHANNEL

10.1 Design Flood

During the Master Plan Study of flood control on 4 major Viti Levu rivers, the design flood of each watershed has been determined considering the area of watershed, social and economic importance of objective area, flood damage expected and so on. The result of design flood determination is discussed briefly below.

As a result of examination of watershed indices, such as area of watershed, area of inundation, population and properties in inundated area etc., the flood of 50 year return period is considered appropriate as the design flood of 4 watersheds, Rewa, Sigatoka, Nadi and Ba. However, to achieve the safety degree against 1/50 probability flood, the flow capacity of Rewa, Sigatoka and Ba rivers has to be improved approximately twice as much as the current capacity, while that of Nadi has to be improved 10 times more.

When the difference between the current flow capacity and design flood discharge is very large, the flood control plans often encounter the difficulty of implementation due to the large investment and works to be required. Under this kind of circumstances, the stepwise plans are practical and effective to flood control. Therefore, two step plan has been proposed. The first step is to improve the flow capacity by 50 % of insufficient capacity (= 1/50 probability flood - current flow capacity) and at the second step, the river is improved to drain 1/50 probability flood. Since the flood probability of first step target is almost 1/20 throughout the four watersheds, the flood of 20 year return period was set as a goal of the first step and the Master Plan on flood control was formulated for the first step, 1/20 probability flood.

For the Feasibility Study, the same design flood as the Master Plan is applied to examine the project specifications of Nadi diversion channel and short cut channel. The distribution of design flood discharge, 1/20 probability flood, in Nadi river is shown in Figure-E10.1.

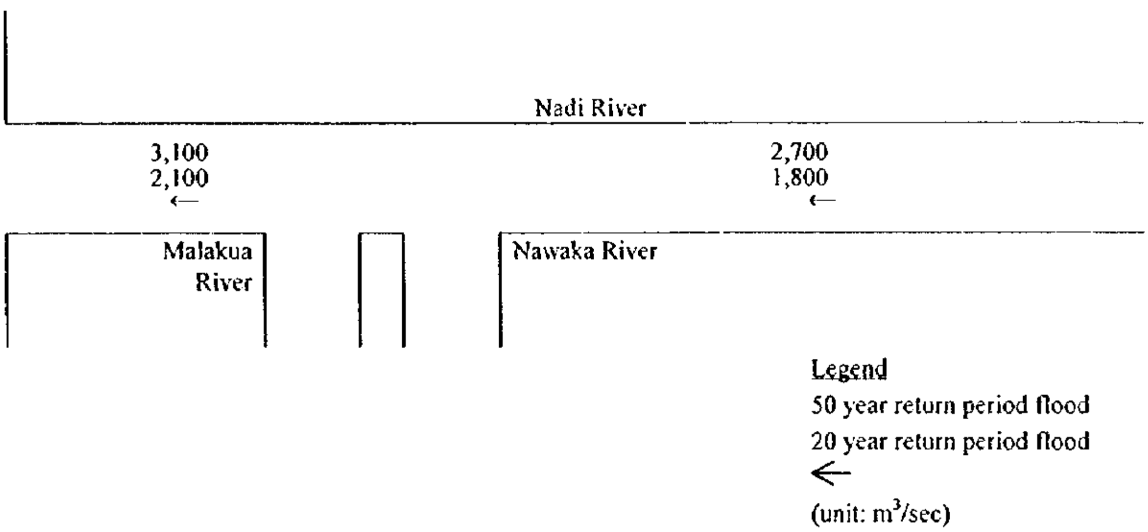


Figure-E10.1 Distribution of Flood Discharge

10.2 Scale of Diversion Channel

The distribution of design flood discharge, 20 year return period flood, with implementation of the diversion channel is shown in Figure-E10.2.

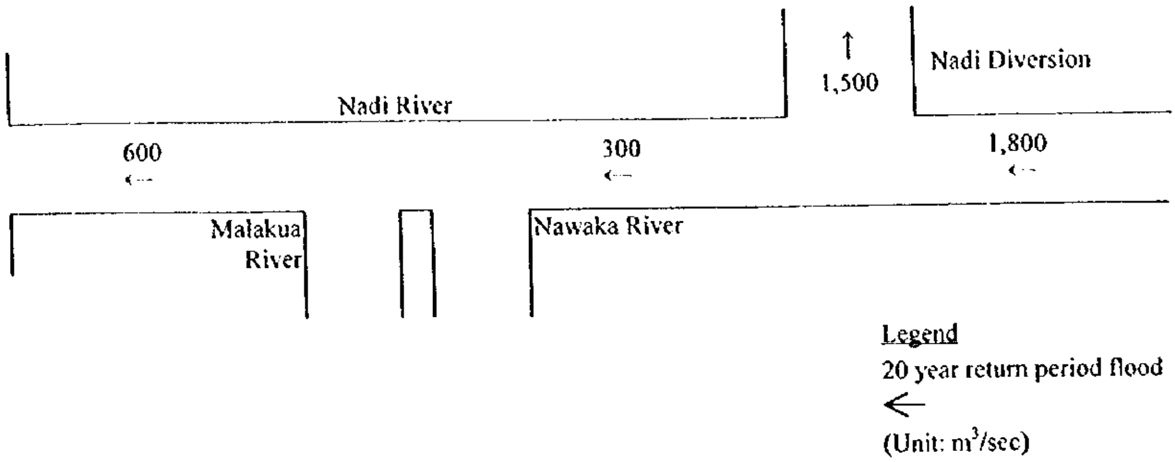


Figure-E10.2 Distribution of Design Flood Discharge (1/20 Probability Flood) with Diversion Channel

As shown in Figure-E10.2, the flow capacity of the diversion channel is 5 times as much as the current flow capacity of Nadi river as long as the design flood is 1/20 probability flood. Even 1/20 probability flood may be too large to realize flood control measures for Nadi river in terms of finance. Therefore, the stepwise implementation of the Nadi diversion channel was examined. To assess the possibility of stepwise implementation of the diversion channel, the scale of diversion channel with smaller probability floods, 1/15, 1/10 and 1/5, was examined. The distribution of different flood discharges with implementation of the diversion channel is shown in Figure-E10.3.

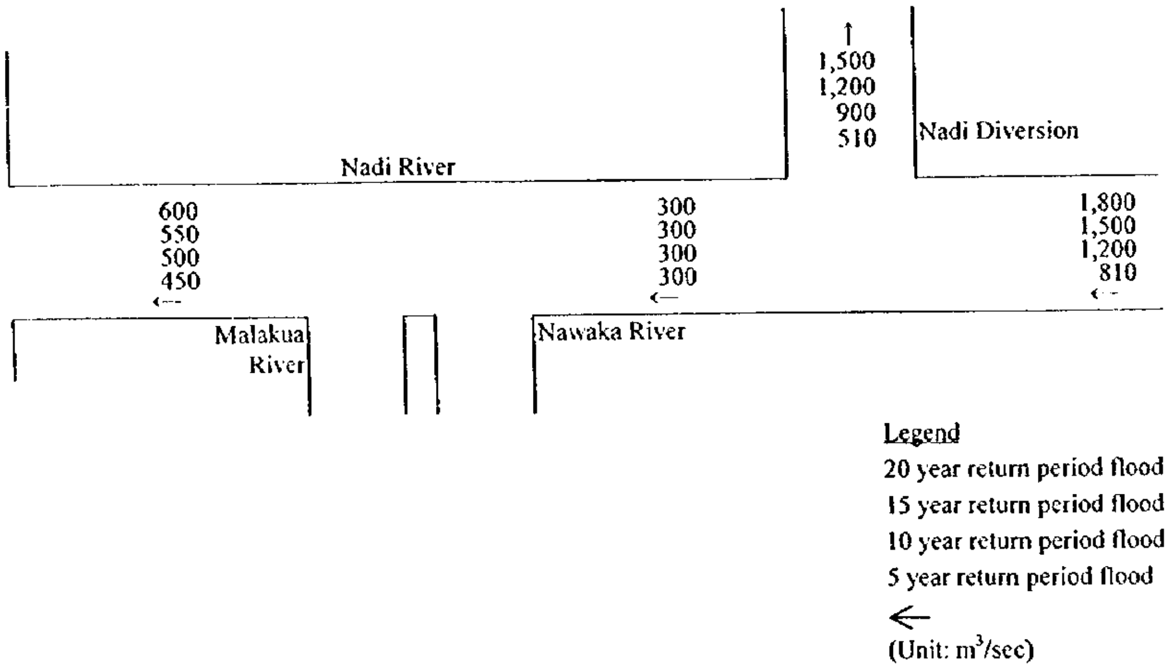


Figure-E10.3 Distribution of Different Flood Discharges with Diversion Channel

A diversion channel for a smaller flood than 1/20 probability flood was designed to have the same longitudinal profile as the diversion channel for 1/20 probability flood but smaller channel width depending on flood discharge, in order to implement the stepwise construction smoothly. The standard cross section of diversion channel for each flood probability is shown in Figure-E10.4. The hydraulic design of those diversion channels is discussed in Chapter 11.

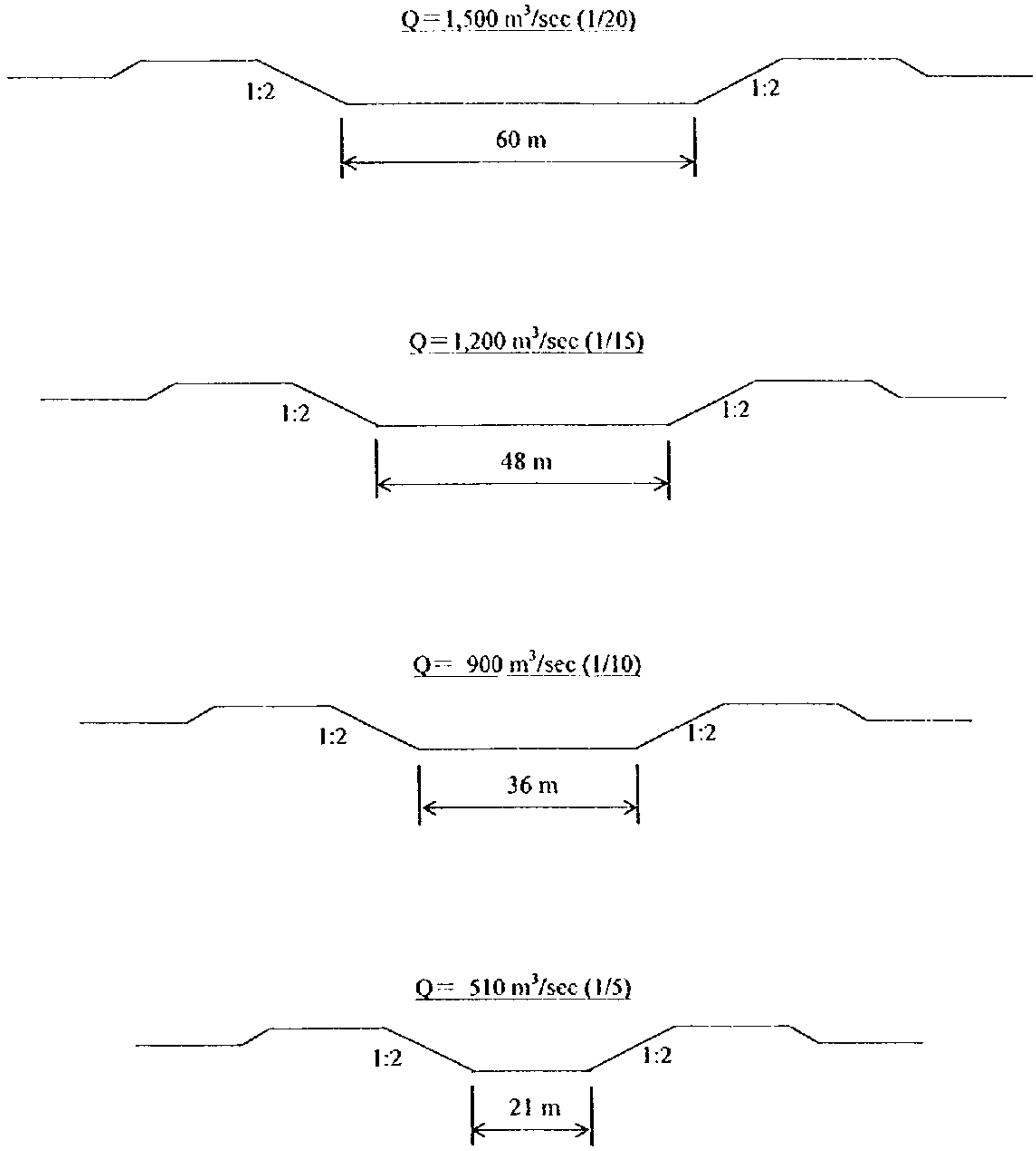


Figure-E10.4 Standard Cross Section of Nadi Diversion Channel for Different Flood Probability

Feasibility Study on

Nadi Diversion Channel & Short Cut Channel

CHAPTER 11 HYDRAULIC DESIGN

11.1 Site for Diversion Channel and Short Cut Channel

(1) Site for Diversion Channel

4 possible alignments which are located upstream Nadi river from the Nadi town (9.5 km ~ 12.0 km upstream from river mouth) were examined for the Nadi diversion channel in terms of topographical features, land acquisition and length (Chapter 4). As a result, an alignment which passes along the Enamanu road and whose total length is the shortest among 4 alignments was selected.

Based on results of topographical survey, geological survey and social-environmental survey conducted during the 3rd work period in Fiji from November 1997 to March 1998, the alignment of the diversion channel was finally determined. Items considered for the determination of alignment are topographical features, geological features, land acquisition and compensation and preservation areas, such as cemetery, archaeological site etc., in the project site. As a result, the diverting point is the right bank of Nadi river located at 14.6 km from river mouth and the total length is approximately 3.3 km. These figures are slightly different from the Master Plan (diverting point: 14.0 km from river mouth, total length: 3.0 km).

(2) Site for Short Cut Channel

Based on results of topographical survey and social-environmental survey conducted during the 3rd work period in Fiji, the site for the short cut channel was finally determined. In fact, the site is not different from that proposed in the Master Plan because there is no land use practiced in the site.

The short cut channel will connect between 7.5 km and 9.0 km points of Nadi river from river mouth. Its total length is approximately 250 m.

(3) Location

Location of the Nadi diversion channel and short cut channel are shown in Figure-E11.1

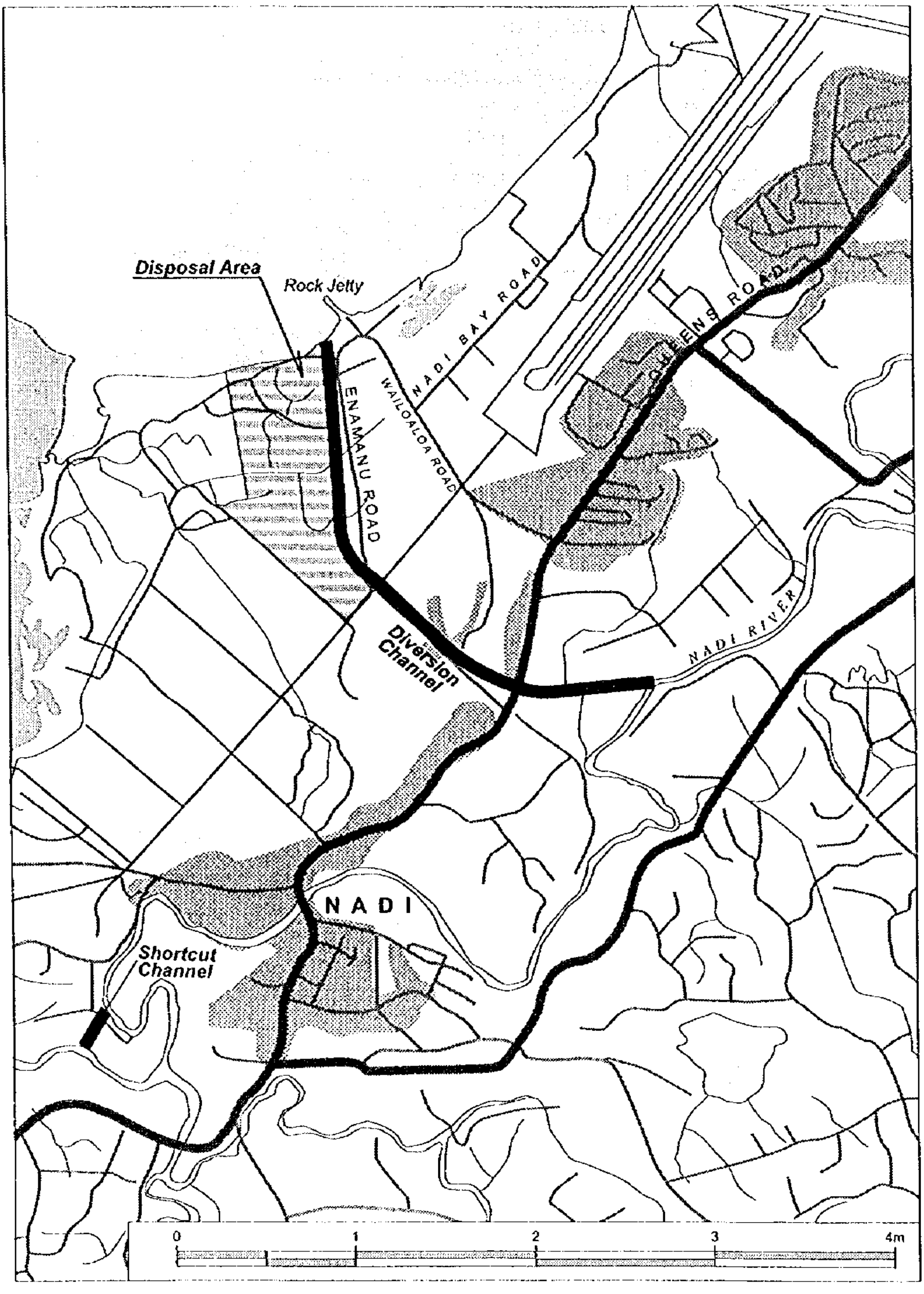


Figure-E11.1 Location of Nadi Diversion Channel and Short Cut Channel

11.2 Diverting Ratio

According to daily rainfall data at Nadi airport in the last 53 years (1942 ~ 1995, data gaps in 1946), annual rainy days are 130 days in average, 84 days in the least and 178 days in the greatest. Therefore, rainfall contributes to discharge for 23 % ~ 49 % of year. As shown in Figure-E11.3 (flow regime), discharge is almost constant for 50 % of year (50 % from the lowest discharge) and it implies that there is no runoff to affect discharge by rainfall. Discharge at 25 % of year from the maximum is approximately 3 times bigger than discharge when there is no rainfall and it is apparent that this increase is due to rainfall.

Diverting ratio was determined as drainage through the diversion channel starts when discharge of Nadi river increases by rainfall. Considering the rainfall distribution in year and flow regime, the diversion channel was designed to start drainage when discharge of Nadi river is approximately 15 m^3/sec which is discharge at 25 % of year from the maximum, allowing Nadi river to drain water for 75 % of year without the diversion channel. For the rest of year, 25 % of year, water is drained by both Nadi river and diversion channel varying the diverting ratio. Diverting ratios with different discharge were determined by non-uniform flow calculation and the result is shown in Figure-E11.2.

Based on the flow regime at Votualevu station (catchment area = 164 km^2), the flow regime at the diverting point (catchment area = 327 km^2) was estimated by ratio of catchment area. The result is shown in Figure-E11.3.

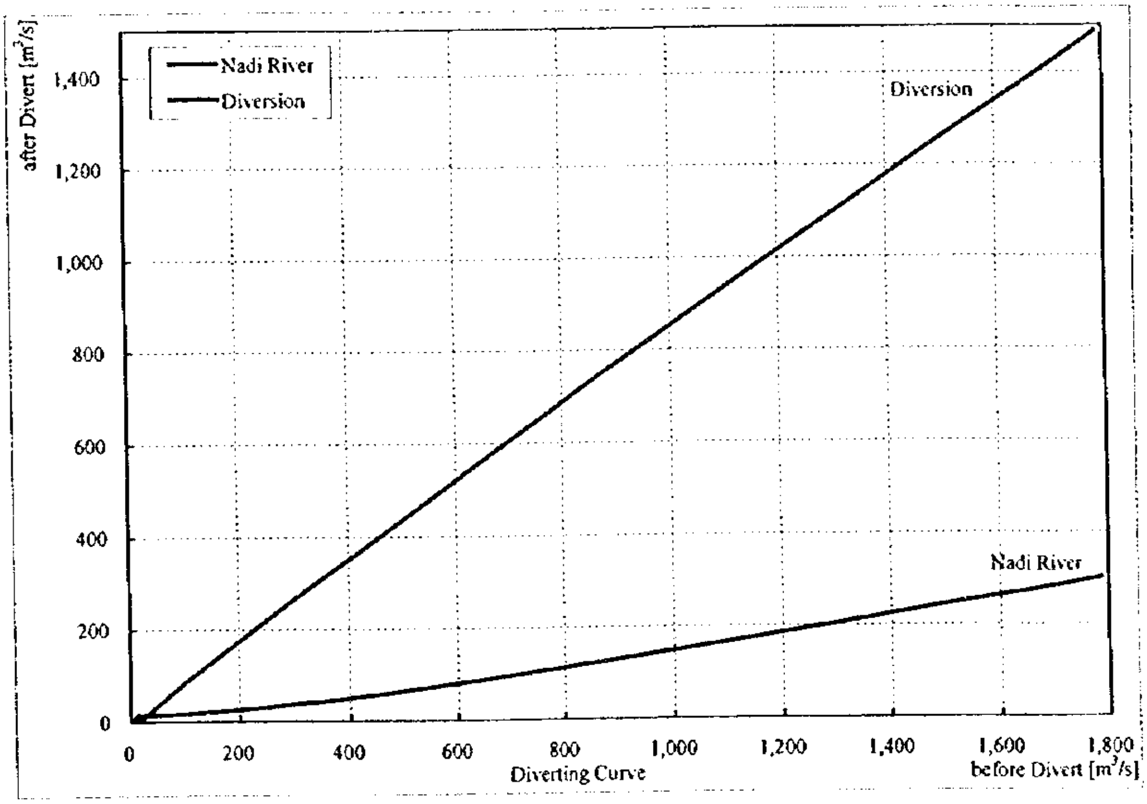


Figure-E11.2 Diverting Ratio of Nadi River and Diversion Channel

Votualevu (HA020) : Nadi River

Catchment Area : 164 km^2

Year	Max	Q1.4%	Q 2.7%	Q 4.1%	Q 5.5%	Q 8.2%	Q 11.0%	Q 13.7%	Q 16.4%	Q 19.2%	Q 26.0%	Q 50.7%	Q 75.3%	Q 97.3%
1980	127.0	43.2	25.2	19.0	15.8	12.3	10.1	8.4	7.8	6.6	4.5	1.1	0.5	0.5
1981	127.3	69.5	36.4	32.0	25.1	14.3	9.4	7.6	6.5	5.6	4.3	1.3	0.7	0.6
1982	415.0	63.0	31.2	28.7	24.1	18.0	15.3	12.9	10.8	9.6	5.9	0.7	0.2	0.1
1984	87.6	30.7	22.3	17.5	16.1	14.5	12.7	11.8	11.2	10.6	9.5	5.7	2.6	2.3
1986	378.0	70.9	36.1	33.8	26.4	19.0	14.8	12.2	10.4	9.5	6.6	4.5	4.2	4.2
1988	84.0	19.5	16.5	11.3	10.9	8.9	8.9	8.5	8.2	8.0	7.7	3.2	2.3	2.2
Ave.	203.2	49.5	28.0	23.7	19.7	14.5	11.9	10.2	9.2	8.3	6.4	2.8	1.8	1.7

Diverting Point of Nadi River

Catchment Area : 327 km2

Year	Max	Q1.4%	Q 2.7%	Q 4.1%	Q 5.5%	Q 8.2%	Q 11.0%	Q 13.7%	Q 16.4%	Q 19.2%	Q 26.0%	Q 50.7%	Q 75.3%	Q 97.3%
1980	253.2	86.1	50.2	37.9	31.5	24.5	20.1	16.7	15.6	13.2	9.0	2.2	1.0	1.0
1981	253.8	138.6	72.6	63.8	50.0	28.5	18.7	15.2	13.0	11.2	8.6	2.6	1.4	1.2
1982	827.5	125.6	62.2	57.2	48.1	35.9	30.5	25.7	21.5	19.1	11.8	1.4	0.4	0.2
1984	174.7	61.2	44.5	34.9	32.1	28.9	25.3	23.5	22.3	21.1	18.9	11.4	5.2	4.6
1986	753.7	141.4	72.0	67.4	52.6	37.9	29.5	24.3	20.7	18.9	13.2	9.0	8.4	8.4
1988	167.5	38.9	32.9	22.5	21.7	17.7	17.7	16.9	16.4	16.0	15.4	6.4	4.6	4.4
Ave.	405.1	98.6	55.7	47.3	39.3	28.9	23.7	20.4	18.2	16.6	12.8	5.5	3.5	3.3

Diverting Point = Votualevu x 327/164

Q 1.4% : daily discharge exceeding this volume for 1.4 % of a year (5 days) or 5th daily discharge from the maximum

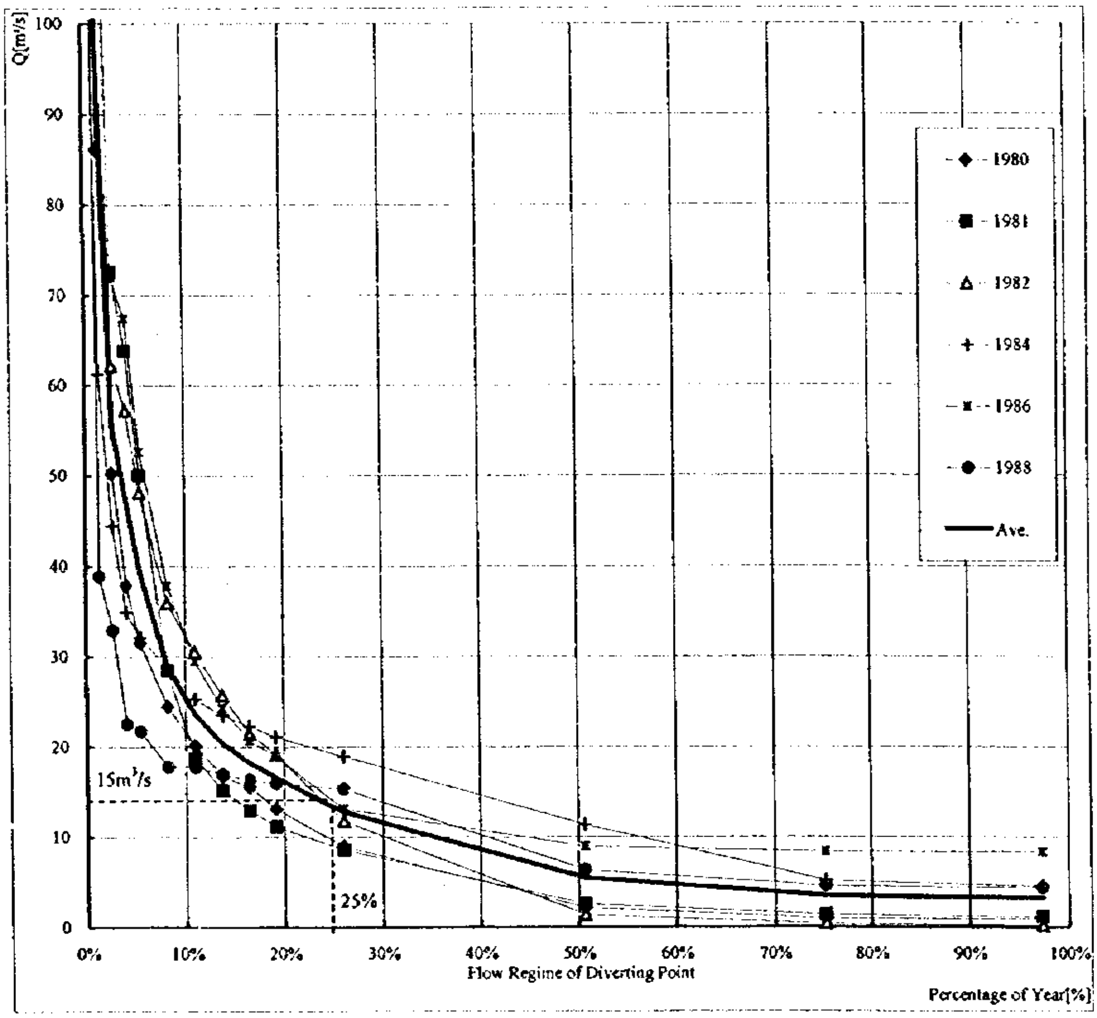


Figure-E11.3 Flow Regime at Diverting Point in Nadi River

11.3 Hydraulic Design of Diversion Channel and Short Cut Channel

11.3.1 Design Conditions

(1) Functions of Diversion Channel

The Nadi diversion channel has the following functions.

- 20 year return period flood at diverting point (1,800 m^3/sec) is drained through the diversion channel (1,500 m^3/sec) and Nadi river (300 m^3/sec).
- Drainage through the diversion channel starts, when discharge of Nadi river is increased by rainfall and is 15 m^3/sec.

(2) Consideration of Design

For the design, following 2 items were considered.

- to minimize width of the diversion channel in order to reduce work quantity and cost
- to design bed elevation of the diversion channel as high as possible in order to reduce work quantity in the sea resulting cheaper cost

(3) Design Method

Method to examine the hydraulic design of the Nadi diversion channel is as follows.

1) to determine widths of the diversion channel inlet and Nadi river at diverting point so as to allocate floods in accordance with the design

Table-E11.1 Widths of Inlet and Nadi River at Diverting Point

Width	Case 1 (m)	Case 2 (m)	Case 3 (m)	Case 4 (m)
Nadi River	9	10	11	12
Diversion Channel	54	60	65	71

Width of the diversion channel is required at least 50 ~ 70 m based on topographic condition and discharge.
Width of Nadi river was determined based on width of the diversion channel.

2) to calculate water level and energy head of Nadi river form river mouth to diverting point by non-uniform flow computation with the above conditions (Table-E11.1)
3) to calculate water level and energy head of the diversion channel from downstream end to diverting point by non-uniform flow computation
4) to conduct 3) calculation varying hydraulic specifications (cross section and longitudinal profile) of the diversion channel until water levels and energy heads of the diversion channel and Nadi river are equal to each other at diverting point
5) to select the hydraulic specification whose width is equal to inlet width of the diversion channel among several specifications determined in 4)

(4) Design Conditions

The followings are design conditions of the diversion channel.

1) Sea water level: Since the mean high water of tide is approximately EL. 0.6 m (above mean sea level), EL. 1.0 m was adopted as a boundary condition of non-uniform flow computation considering the safety factor.

2) Calculation in the sea around the downstream end: Assuming that flow from the diversion channel spreads with an angle of 5°, a staring point of non-uniform flow computation where velocity of the flow is dissipated is 1.5 km away from the downstream end. The angle of 5° is the popular empirical figure.

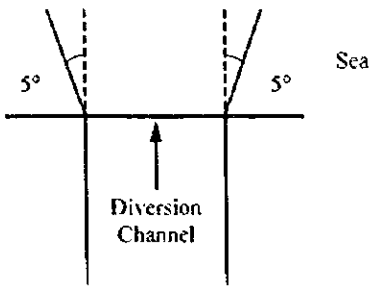


Figure-E11.4 Spreading Angle of Flow into Sea

3) Slope gradient of diversion channel: Considering slope stability of the diversion channel and vegetation cover on slope, slope gradient is assumed to be 1:2.

4) Manning roughness coefficient: Manning roughness coefficient in Nadi river and the diversion channel is assumed to be 0.03.

5) Bed elevation at diverting point: Bed elevation of Nadi river is equal to the present bed elevation (EL. -1.0 m), while bed elevation of the diversion channel is EL. 0.0 m which water starts to flow into the diversion channel when discharge of Nadi river is 15 m^3/sec.

11.3.2 Results

(1) Diversion Channel

Based on the conditions above, non-uniform flow computation was employed to determine the hydraulic design of the diversion channel varying widths of inlet and Nadi river at diverting point. The results are shown in Table-E11.2.

Table-E11.2 (1/2) Hydraulic Design of Diversion Channel with Target Water Level and Energy Head

Nadi River	Target (case 1)		Width of Diverting Point	
	H (EL. m)	4.98	Nadi River:	9 m
	V (m/s)	5.54	Inlet of Diversion Channel:	54 m
	E (EL. m)	6.57		

Diversion Channel	Elevation of Outlet (EL. m)	Item	Section of Diversion Channel where Bed Slope is Flat: No Flat Section	0 ~ 1,300 m	0 ~ 1,800 m	0 ~ 2,300 m	
	-2.0	B (m)				100.0	
		H (EL. m)				4.99	
		V (m/s)				5.56	
		E (EL. m)				6.57	
	-2.5	B (m)			100.0	69.5	
		H (EL. m)			5.27	4.98	
		V (m/s)			5.27	5.58	
		E (EL. m)			6.69	6.57	
	-3.0	B (m)		100.0	100.0	55.5	
		H (EL. m)		5.48	5.01	4.98	
		V (m/s)		5.07	5.54	5.58	
		E (EL. m)		6.79	6.58	6.57	

Nadi River	Target (case 2)		Width of Diverting Point	
	H (EL. m)	5.22	Nadi River:	10 m
	V (m/s)	4.82	Inlet of Diversion Channel:	60 m
	E (EL. m)	6.41		

Diversion Channel	Elevation of Outlet (EL. m)	Item	Section of Diversion Channel where Bed Slope is Flat: No Flat Section	0 ~ 1,300 m	0 ~ 1,800 m	0 ~ 2,300 m	0 ~ 2,500 m
	-2.0	B (m)		100.0		77.8	
		H (EL. m)		5.85		5.22	
		V (m/s)		4.30		4.82	
		E (EL. m)		6.80		6.41	
	-2.5	B (m)		100.0	80.5	63.0	60.0
		H (EL. m)		5.54	5.22	5.22	5.24
		V (m/s)		4.54	4.82	4.82	4.78
		E (EL. m)		6.59	6.41	6.41	6.40
	-3.0	B (m)		100.0	60.0		
		H (EL. m)		5.27	5.22		
		V (m/s)		4.78	4.82		
		E (EL. m)		6.43	6.41		

Nadi River	Target (case 3)		Width of Diverting Point	
	H (EL. m)	5.38	Nadi River:	11 m
	V (m/s)	4.28	Inlet of Diversion Channel:	65 m
	E (EL. m)	6.31		

Diversion Channel	Elevation of Outlet (EL. m)	Item	Section of Diversion Channel where Bed Slope is Flat: No Flat Section	0 ~ 1,300 m	0 ~ 1,800 m	0 ~ 2,300 m	
	-2.0	B (m)		100.0	88.5	72.6	
		H (EL. m)		5.66	5.37	5.38	
		V (m/s)		4.07	4.28	4.28	
		E (EL. m)		6.50	6.31	6.31	
	-2.5	B (m)		93.9	67.1		
		H (EL. m)		5.37	5.37		
		V (m/s)		4.28	4.28		
		E (EL. m)		6.31	6.31		
	-3.0	B (m)		66.2			
		H (EL. m)		5.37			
		V (m/s)		4.29			
		E (EL. m)		6.30			

Table-E11.2 (2/2) Hydraulic Design of Diversion Channel with Target Water Level and Energy Head

Nadi River		Target (case 4)		Width of Diverting Point Nadi River: 12 m Inlet of Diversion Channel: 71 m			
		H (EL. m)	5.48				
		V (m/s)	3.86				
		E (EL. m)	6.24				
Diversion Channel	Elevation of Outlet (EL. m)	Item	Section of Diversion Channel where Bed Slope is Flat				
			No Flat Section	0 ~ 1,300 m	0 ~ 1,800 m	0 ~ 2,300 m	
	-2.0	B (m)					
		H (EL. m)					
		V (m/s)					
		E (EL. m)					
	-2.5	B (m)		100.0	96.5	66.4	
		H (EL. m)		5.85	5.48	5.48	
		V (m/s)		3.61	3.85	3.85	
		E (EL. m)		6.52	6.24	6.24	
	-3.0	B (m)	100.0				
		H (EL. m)	6.14				
		V (m/s)	3.46				
		E (EL. m)	6.75				

B: Bed Width of Diversion Channel
H: Water Level at Diverting Point
V: Velocity
E: Energy Head

Distance is counted from the downstream end.
Note: In the case that energy head exceeds the target despite the fact that bed width of the diversion channel is 100 m, calculation was ceased because the bed width greater than 100 m is too large scale to be implemented.

1) In the case that inlet width is 54 m, the hydraulic design to satisfy diversion conditions is that bed elevation of the diversion channel at downstream end is EL. -3.0 m and section from downstream end to 2,300 m is flat. In case that the bed elevation at downstream end is higher than EL. -3.0 m, the diversion channel cannot drain the expected discharge even if all section of the diversion channel is designed flat.

2) In the case that inlet width is 60 m, there are two designs to satisfy diversion conditions. One is that bed elevation of the diversion channel at downstream end is EL. -2.5 m and section from downstream end to 2,500 m is flat, and another is that bed elevation at downstream end is EL. -3.0 m and section from downstream end to 1,800 m is flat.

3) In the case that inlet width is 65 m, there are two designs to satisfy diversion conditions. One is that bed elevation of the diversion channel at downstream end is EL. -2.5 m and section from downstream end to 1,800 m is flat, and another is that bed elevation at downstream end is EL. -3.0 m and section from downstream end to 1,300 m is flat.

4) In the case that inlet width is 71 m, the hydraulic design to satisfy diversion conditions is that bed elevation of the diversion channel at downstream end is EL. -2.5 m and section from downstream end to 1,800 ~ 2,300 m is flat.

Bed elevation of the diversion channel should be as high as possible in terms of construction of outlet in the sea, while bed width should be narrow in terms of work quantity or construction cost. The case 1 has the smallest bed width; however, bed elevation at downstream end (EL. -3.0 m) has a disadvantage. If bed elevation is EL. -2.5 m, the smallest bed width is 60 m (case 2). Therefore, considering the construction of outlet and cost of the diversion channel, the case 2 (the following specifications) was adopted as the hydraulic design of the diversion channel.

–	bed width of diversion channel:	60 m
–	bed elevation at downstream end:	EL. -2.5 m
–	flat section of bed:	from downstream end to 2,500 m

Details of the hydraulic design are summarized in Table-E11.3 for not only the design flood (1/20 probability flood) but also 1/15, 1/10 and 1/5 probability floods. The hydraulic analysis was conducted for the target flood (1/20 probability flood) only. Since diversion channels for other smaller floods have same bed slope as the diversion channel for 1/20 probability flood but smaller bed width depending on flood discharge and the hydraulic phenomena for other smaller floods are almost similar to that for 1/20 probability flood, it is not necessary at present to conduct the hydraulic analysis for 1/15, 1/10 and 1/5 probability floods.

(6) Short Cut Channel

The short cut channel has 250 m length connecting 7.5 km point and 9.0 km point of Nadi river from river mouth. Longitudinal profile was designed to be equivalent to the current one of Nadi river (1/2,000) and bed elevation was also designed to be same as bed elevation of Nadi river (7.5 km point: EL. -1.0 m and 9.0 km point: EL. -0.9 m). Bed width of the short cut channel was determined as 30 m which is same as bed width of Nadi river at 9.0 km point, while bed width of Nadi river at 7.5 km was designed to be enlarged to 40 m considering confluence with Nawaka river.

Details of the hydraulic design are shown in Table-E11.3.

Table-E11.3 Summary of Hydraulic Design (Diversion Channel and Short Cut Channel)

Item			Probability of Design Flood			
			1/20	1/15	1/10	1/5
Discharge	NR upstream DC		1,800 m^3/sec	1,500 m^3/sec	1,200 m^3/sec	810 m^3/sec
	NR downstream DC		300 m^3/sec	300 m^3/sec	300 m^3/sec	300 m^3/sec
	Diversion		1,500 m^3/sec	1,200 m^3/sec	900 m^3/sec	510 m^3/sec
	Start of diverting		15 m^3/sec	15 m^3/sec	15 m^3/sec	15 m^3/sec
Diverting Point	Location of diverting		Nadi river 14.6 km upstrem from river mouth			
	Bed slope		1/5,000			
	Bed elevation		EL. -1.00 m			
	Width of NR (bed)		10.0 m	10.0 m	10.0 m	10.0 m
	Width of inlet (DC)		60.0 m	48.0 m	36.0 m	21.0 m
	WL at inlet		EL. 5.145 m	EL. 5.019 m	EL. 4.899 m	EL. 4.787 m
	WL at inlet without DC		(EL. 13.041 m)	(EL. 11.971 m)	(EL. 10.799 m)	(EL. 10.313 m)
	Total head		EL. 6.361 m	EL. 6.286 m	EL. 6.219 m	EL. 6.158 m
	Velocity		4.88 m/sec	4.98 m/sec	5.09 m/sec	5.18 m/sec
	Froude number		0.63	0.65	0.67	0.69
Diversion Channel	Total length		approximately 3,300 m			
	Bed slope		downstrem from 2.5 km point : Level			
			upstream from 2.5 km point : 1/320			
	Elevation at downstream end		EL. -2.500 m			
	Elevation of inlet		EL. 0.000 m			
	Bed width		60.0 m	48.0 m	36.0 m	21.0 m
Short Cut Channel	Location		between 7.5 km and 9.0 km of Nadi river from river mouth (length : 250 m)			
	Bed slope		1/2,500			
	Bed elevation	7.5 km	EL. -1.000 m			
		9.0 km	EL. -0.900 m			
	Bed width	7.5 km	40.0 m			
		Short cut	30.0 m			
	WL at 9.0 km point		EL. 4.810 m	EL. 4.607 m	EL. 4.395 m	EL. 4.174 m
	WL at 9.0 km poit with DC without short cut		(EL. 5.147 m)	(EL. 4.957 m)	(EL. 4.764 m)	(EL. 4.547 m)
	Velocity		1.27 m/sec	1.33 m/sec	1.40 m/sec	1.47 m/sec
	Froude number		0.19	0.20	0.22	0.23

NR: Nadi River

DC: Diversion Channel

WL: Water Level

(3) Water Level

Non-uniform flow computation was applied to estimate water level of Nadi river for 20 year return period flood with implementation of the diversion and short cut channels. Results are summarized in Table-E11.4 and expected water level is shown in Figure-E11.5. Water level of the diversion channel for the design discharge (1,500 m^3/sec) was also estimated by non-uniform flow computation and results are shown in Table-E11.5 and Figure-E11.6.

Since width of Nadi river is narrowed to 10 m at diverting point, velocity of flow increases resulting in lower water level (velocity head + water level = energy head: approximately constant). However, the flow does not become turbulent because it is not supercritical flow.

Nadi river upstream from diverting point is improved to flow 2,100 m^3/sec; however, Nadi river is very narrow in further upstream. Therefore, as shown in Figure-E11.5, water level around 15 km point is much higher than downstream due to backwater resulting from the narrow areas.

Bed slope of the diversion channel is flat from downstream end to 2,500 m point as shown in Figure-E11.6; however, there is no stagnation during drainage even if discharge is small because flow is governed by not bed slope but energy gradient.

(4) Recommendation

Hydraulic design of the diversion channel and short cut channel in this study was conducted by one dimensional analysis. Since Nadi river is a natural channel which does not have uniform cross section and objective of hydraulic calculation is flood whose velocity is very fast, it is not possible to get expected accuracy of hydraulic examination by two or three dimensional analysis. Therefore, hydraulic model experiment would be strongly recommended to reexamine the design of the diversion and short cut channels, to understand flow conditions (area of water collision etc.) and to study sediment transportation if the diversion and short cut channel project were determined to be implemented.

Table-E11.4 Water Level of Nadi River with Diversion & Short Cut Channels
(1/20 Probability Flood)

Name	dX (m)	Accumlated Distance	Q (m^3/s)	H bed (m)	H (m)	V.H (m)	total E (m)	IE	A (m^2)	B (m)	R (m)	A/B (m)	n	alpha	V (m/s)	Fr
NADI 600	600	600	600	-5.42	1.000	0.034	1.034	2.14E-04	738.625	342.28	2.15	2.16	0.03	1.00	0.81	0.18
NADI 1,000	400	1,000	600	-3.59	1.092	0.188	1.280	1.02E-03	312.185	127.74	2.43	2.44	0.03	1.00	1.92	0.39
NADI 1,500	500	1,500	600	-4.12	1.536	0.162	1.698	6.51E-04	337.232	109.59	3.03	3.08	0.03	1.00	1.78	0.32
NADI 2,000	500	2,000	600	-4.13	1.861	0.171	2.032	6.85E-04	327.502	104.91	3.04	3.12	0.03	1.00	1.83	0.33
NADI 2,500	500	2,500	600	-3.10	2.201	0.103	2.304	4.02E-04	422.669	133.64	3.10	3.16	0.03	1.00	1.42	0.25
NADI 3,000	500	3,000	600	-2.75	2.431	0.090	2.522	4.70E-04	450.791	176.89	2.50	2.55	0.03	1.00	1.33	0.27
NADI 3,500	500	3,500	600	-3.77	2.589	0.219	2.808	6.75E-04	289.504	73.77	3.70	3.92	0.03	1.00	2.07	0.33
NADI 4,000	500	4,000	600	-1.00	3.018	0.213	3.231	1.02E-03	293.520	107.58	2.67	2.73	0.03	1.00	2.04	0.40
NADI 4,500	500	4,500	600	-1.45	3.447	0.132	3.579	3.76E-04	372.611	91.20	3.93	4.09	0.03	1.00	1.61	0.25
NADI 5,000	500	5,000	600	-1.00	3.684	0.095	3.779	4.23E-04	440.216	154.37	2.80	2.85	0.03	1.00	1.36	0.26
NADI 5,500	500	5,500	600	-1.00	3.840	0.214	4.054	6.77E-04	292.974	76.32	3.63	3.84	0.03	1.00	2.05	0.33
NADI 6,000	500	6,000	600	-1.82	4.198	0.085	4.283	2.38E-04	464.284	112.62	3.98	4.12	0.03	1.00	1.29	0.20
NADI 6,500	500	6,500	600	-1.00	4.328	0.093	4.421	3.14E-04	443.956	123.96	3.46	3.58	0.03	1.00	1.35	0.23
NADI 7,000	500	7,000	600	-1.52	4.447	0.159	4.606	4.26E-04	339.940	77.29	4.11	4.40	0.03	1.00	1.77	0.27
NADI 7,500	500	7,500	600	-1.00	4.626	0.207	4.833	4.82E-04	298.173	62.51	4.56	4.77	0.03	1.00	2.01	0.29
NADI SC-1	50	7,550	300	-0.98	4.770	0.081	4.850	2.05E-04	238.608	53.00	4.28	4.50	0.03	1.00	1.26	0.19
NADI SC-2	50	7,600	300	-0.96	4.779	0.081	4.860	2.06E-04	238.070	52.96	4.28	4.50	0.03	1.00	1.26	0.19
NADI SC-3	50	7,650	300	-0.94	4.789	0.081	4.871	2.07E-04	237.541	52.92	4.27	4.49	0.03	1.00	1.26	0.19
NADI SC-4	50	7,700	300	-0.92	4.799	0.082	4.881	2.09E-04	237.015	52.88	4.26	4.48	0.03	1.00	1.27	0.19
NADI 9,000	50	7,750	300	-0.90	4.810	0.082	4.892	2.10E-04	236.492	52.84	4.26	4.48	0.03	1.00	1.27	0.19
NADI 9,500	500	8,250	300	-2.07	4.931	0.057	4.988	1.75E-04	283.775	73.63	3.72	3.85	0.03	1.00	1.06	0.17
NADI 10,000	500	8,750	300	-1.00	5.022	0.042	5.064	1.29E-04	331.877	87.48	3.69	3.79	0.03	1.00	0.90	0.15
NADI 10,500	500	9,250	300	-3.35	5.077	0.039	5.117	8.30E-05	344.226	64.79	4.93	5.27	0.03	1.00	0.88	0.12
NADI 11,000	500	9,750	300	-1.09	5.110	0.070	5.180	1.70E-04	255.889	54.82	4.42	4.67	0.03	1.00	1.17	0.17
NADI 11,500	500	10,250	300	-1.53	5.206	0.049	5.255	1.29E-04	304.753	70.09	4.18	4.35	0.03	1.00	0.98	0.15
NADI 12,000	500	10,750	300	-1.58	5.258	0.091	5.349	2.45E-04	225.082	51.49	4.09	4.37	0.03	1.00	1.33	0.20
NADI 12,500	500	11,250	300	-0.81	5.377	0.089	5.466	2.26E-04	226.534	49.21	4.29	4.60	0.03	1.00	1.32	0.20
NADI 13,000	500	11,750	300	-0.90	5.487	0.097	5.584	2.45E-04	217.167	46.54	4.31	4.67	0.03	1.00	1.38	0.20
NADI 13,500	500	12,250	300	-2.67	5.600	0.105	5.704	2.36E-04	209.486	40.72	4.68	5.14	0.03	1.00	1.43	0.20
NADI 14,000	500	12,750	300	-2.20	5.750	0.046	5.797	1.34E-04	315.003	78.53	3.88	4.01	0.03	1.00	0.95	0.15
NADI 14,500	500	13,250	300	-1.02	5.755	0.287	6.041	8.46E-04	126.565	27.36	3.82	4.63	0.03	1.00	2.37	0.35
NADI A14600	100	13,350	300	-1.00	5.145	1.216	6.361	5.55E-03	61.453	10.00	2.76	6.15	0.03	1.00	4.88	0.63
*NADI B14600	0	13,350	1,800	-1.00	5.163	1.198	6.361	2.84E-03	371.395	70.00	4.51	5.31	0.03	1.00	4.85	0.67
NADI 14,650	50	13,400	1,800	-0.99	6.036	0.413	6.449	6.85E-04	632.761	104.11	5.89	6.08	0.03	1.00	2.84	0.37
NADI 14,800	150	13,550	1,800	-0.95	6.012	0.562	6.574	9.73E-04	542.500	91.85	5.70	5.91	0.03	1.00	3.32	0.44
NADI 15,000	200	13,750	1,800	-0.90	6.229	0.531	6.760	8.95E-04	557.936	92.52	5.82	6.03	0.03	1.00	3.23	0.42
NADI 15,500	500	14,250	1,800	-0.80	6.228	1.513	7.741	3.03E-03	330.594	61.35	5.12	5.39	0.03	1.00	5.44	0.75
NADI 16,000	500	14,750	1,800	-0.52	8.559	2.047	10.606	5.90E-03	284.146	69.39	3.89	4.09	0.03	1.00	6.33	1.00
NADI 16,500	500	15,250	1,800	-0.01	11.779	0.455	12.234	6.11E-04	602.921	78.49	6.90	7.68	0.03	1.00	2.99	0.34
NADI 17,000	500	15,750	1,800	-0.93	12.032	0.490	12.522	5.43E-04	580.591	59.39	7.97	9.78	0.03	1.00	3.10	0.32
NADI 17,500	500	16,250	1,800	0.50	12.156	0.726	12.882	8.95E-04	477.229	54.03	7.35	8.83	0.03	1.00	3.77	0.41
NADI 18,000	500	16,750	1,800	0.85	12.817	0.405	13.222	4.64E-04	639.205	70.47	7.76	9.07	0.03	1.00	2.82	0.30
NADI 18,500	500	17,250	1,800	0.75	12.883	0.658	13.540	8.10E-04	501.287	57.71	7.36	8.69	0.03	1.00	3.59	0.39
NADI 19,000	500	17,750	1,800	1.29	13.360	0.540	13.900	6.27E-04	553.265	61.52	7.70	8.99	0.03	1.00	3.25	0.35
NADI 19,500	500	18,250	1,800	0.8[illegible]	13.686	0.539	14.225	6.75E-04	553.792	67.38	7.27	8.22	0.03	1.00	3.25	0.36
NADI 20,000	500	18,750	1,800	2.11	13.858	0.801	14.659	1.06E-03	454.313	53.58	6.98	8.48	0.03	1.00	3.96	0.43
NADI 20,500	500	19,250	1,800	2.16	14.499	0.624	15.124	8.02E-04	514.534	60.85	7.13	8.46	0.03	1.00	3.50	0.38
NADI 21,000	500	19,750	1,800	3.28	14.618	1.008	15.625	1.20E-03	405.012	42.10	7.53	9.62	0.03	1.00	4.44	0.46
NADI 21,500	500	20,250	1,800	3.77	15.575	0.500	16.075	5.93E-04	575.044	67.07	7.57	8.57	0.03	1.00	3.13	0.34
NADI 22,000	500	20,750	1,800	3.96	15.766	0.647	16.413	7.59E-04	505.603	55.76	7.63	9.07	0.03	1.00	3.56	0.38
NADI 22,500	500	21,250	1,800	4.69	16.204	0.559	16.763	6.39E-04	543.949	59.04	7.78	9.21	0.03	1.00	3.31	0.35
NADI 23,000	500	21,750	1,800	3.86	16.699	0.307	17.007	3.37E-04	733.549	80.10	8.04	9.16	0.03	1.00	2.45	0.26
NADI 23,500	500	22,250	1,800	5.85	16.142	1.494	17.637	2.18E-03	332.608	41.48	6.48	8.02	0.03	1.00	5.41	0.61
NADI 24,000	500	22,750	1,800	4.57	17.856	0.448	18.304	4.85E-04	607.670	62.45	8.11	9.73	0.03	1.00	2.96	0.30
NADI 24,500	500	23,250	1,800	5.35	18.169	0.352	18.521	3.86E-04	684.952	74.47	8.03	9.20	0.03	1.00	2.63	0.28
NADI 25,000	500	23,750	1,800	6.58	18.379	0.348	18.727	4.36E-04	688.924	83.94	7.28	8.21	0.03	1.00	2.61	0.29

dx: distance
Q: discharge
H.bed: elevation of river bed
H: water level
V.H: velocity head
total E: total energy head
IE: energy gradient
A: discharge area
B: width of water surface
R: hydraulic radius
A/B: hydraulic depth
n: roughness coefficient
alpha: energy correction coefficient
V: velocity
Fr: Froude number

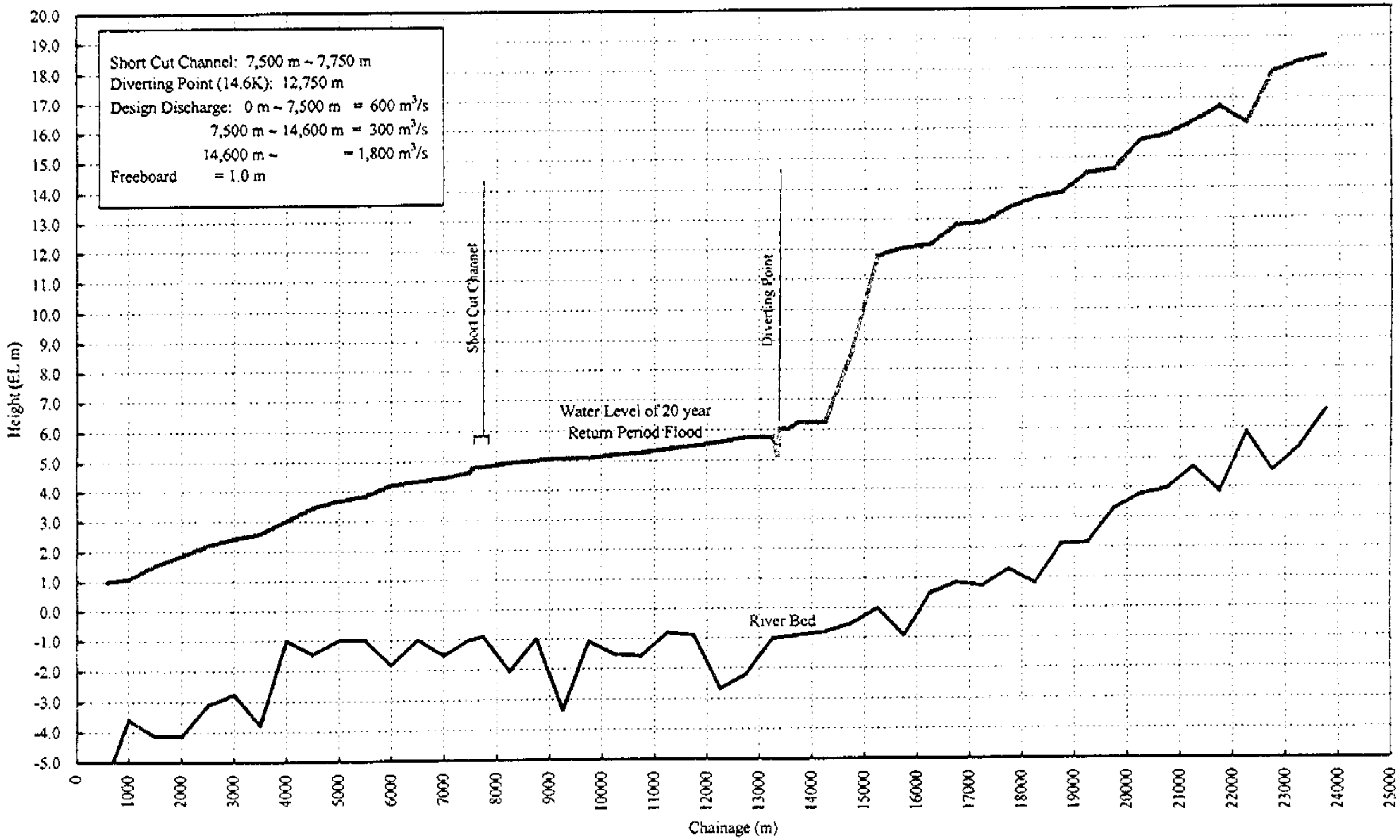


Figure-E11.5 Longitudinal Profile of Nadi River with Expected Water Level

Table-E11.5 Water Level of Diversion Channel (1/20 Probability Flood)

Name		dX (m)	Q (m³/s)	H bed (m)	H (m)	V H (m)	total E (m)	IE	A (m²)	B (m)	R (m)	A/B (m)	n	alpha	V (m/s)	Fr
Nadi-D	-1,500	0	1,500	-5.50	1.000	0.008	1.008	1.13E-05	3,900.000	600.00	6.36	6.50	0.03	1.00	0.38	0.05
Nadi-D	-1,000	500	1,500	-4.50	0.999	0.022	1.020	4.05E-05	2,309.568	420.00	5.36	5.50	0.03	1.00	0.65	0.09
Nadi-D	-500	500	1,500	-3.50	0.994	0.099	1.092	2.47E-04	1,078.455	240.00	4.33	4.49	0.03	1.00	1.39	0.21
Nadi-D	-450	50	1,500	-3.40	0.985	0.121	1.106	3.13E-04	973.499	222.00	4.22	4.39	0.03	1.00	1.54	0.24
Nadi-D	-400	50	1,500	-3.30	0.973	0.151	1.124	4.06E-04	871.729	204.00	4.10	4.27	0.03	1.00	1.72	0.27
Nadi-D	-350	50	1,500	-3.20	0.956	0.192	1.148	5.38E-04	772.960	185.00	3.98	4.16	0.03	1.00	1.94	0.30
Nadi-D	-300	50	1,500	-3.10	0.929	0.251	1.180	7.34E-04	676.883	168.00	3.84	4.03	0.03	1.00	2.22	0.35
Nadi-D	-250	50	1,500	-3.00	0.886	0.338	1.224	1.04E-03	582.934	150.00	3.69	3.89	0.03	1.00	2.57	0.42
Nadi-D	-200	50	1,500	-2.90	0.811	0.478	1.290	1.58E-03	489.890	132.00	3.51	3.71	0.03	1.00	3.06	0.51
Nadi-D	-150	50	1,500	-2.80	0.658	0.739	1.397	2.70E-03	391.176	114.00	3.26	3.45	0.03	1.00	3.81	0.65
Nadi-D	-100	50	1,500	-2.70	0.221	1.460	1.681	6.68E-03	280.377	96.00	2.75	2.92	0.03	1.00	5.35	1.00
Nadi-D	-50	50	1,500	-2.60	0.754	1.677	2.431	6.58E-03	261.628	78.00	3.09	3.35	0.03	1.00	5.73	1.00
Nadi-D	0	50	1,500	-2.50	1.322	1.717	3.039	6.03E-03	258.560	75.29	3.35	3.43	0.03	1.00	5.80	1.00
Nadi-D	50	50	1,500	-2.50	2.172	1.093	3.266	3.03E-03	324.023	78.69	4.01	4.12	0.03	1.00	4.63	0.73
Nadi-D	100	50	1,500	-2.50	2.442	0.962	3.404	2.50E-03	345.358	79.77	4.21	4.33	0.03	1.00	4.34	0.67
Nadi-D	150	50	1,500	-2.50	2.643	0.879	3.521	2.18E-03	361.459	80.57	4.35	4.49	0.03	1.00	4.15	0.63
Nadi-D	200	50	1,500	-2.50	2.807	0.817	3.625	1.95E-03	374.769	81.23	4.48	4.61	0.03	1.00	4.00	0.60
Nadi-D	250	50	1,500	-2.50	2.949	0.769	3.718	1.78E-03	386.328	81.80	4.58	4.72	0.03	1.00	3.88	0.57
Nadi-D	300	50	1,500	-2.50	3.074	0.730	3.804	1.65E-03	396.602	82.30	4.67	4.82	0.03	1.00	3.78	0.55
Nadi-D	350	50	1,500	-2.50	3.187	0.697	3.884	1.54E-03	405.891	82.75	4.75	4.91	0.03	1.00	3.70	0.53
Nadi-D	400	50	1,500	-2.50	3.290	0.668	3.958	1.45E-03	414.462	83.16	4.82	4.98	0.03	1.00	3.62	0.52
Nadi-D	450	50	1,500	-2.50	3.385	0.643	4.029	1.37E-03	422.375	83.54	4.89	5.06	0.03	1.00	3.55	0.50
Nadi-D	500	50	1,500	-2.50	3.474	0.621	4.095	1.30E-03	429.811	83.89	4.96	5.12	0.03	1.00	3.49	0.49
Nadi-D	550	50	1,500	-2.50	3.557	0.602	4.158	1.24E-03	436.785	84.23	5.02	5.19	0.03	1.00	3.43	0.48
Nadi-D	600	50	1,500	-2.50	3.635	0.584	4.219	1.18E-03	443.386	84.54	5.07	5.24	0.03	1.00	3.38	0.47
Nadi-D	650	50	1,500	-2.50	3.709	0.568	4.277	1.13E-03	449.671	84.84	5.12	5.30	0.03	1.00	3.34	0.46
Nadi-D	700	50	1,500	-2.50	3.779	0.553	4.332	1.09E-03	455.640	85.12	5.17	5.35	0.03	1.00	3.29	0.45
Nadi-D	750	50	1,500	-2.50	3.847	0.539	4.386	1.05E-03	461.373	85.39	5.22	5.40	0.03	1.00	3.25	0.45
Nadi-D	800	50	1,500	-2.50	3.911	0.527	4.438	1.01E-03	466.873	85.64	5.26	5.45	0.03	1.00	3.21	0.44
Nadi-D	850	50	1,500	-2.50	3.972	0.515	4.487	9.81E-04	472.144	85.89	5.31	5.50	0.03	1.00	3.18	0.43
Nadi-D	900	50	1,500	-2.50	4.032	0.504	4.536	9.50E-04	477.239	86.13	5.35	5.54	0.03	1.00	3.14	0.43
Nadi-D	950	50	1,500	-2.50	4.089	0.494	4.583	9.22E-04	482.169	86.36	5.39	5.58	0.03	1.00	3.11	0.42
Nadi-D	1,000	50	1,500	-2.50	4.144	0.484	4.628	8.95E-04	486.923	86.58	5.43	5.62	0.03	1.00	3.08	0.41
Nadi-D	1,050	50	1,500	-2.50	4.197	0.475	4.672	8.71E-04	491.517	86.79	5.46	5.66	0.03	1.00	3.05	0.41
Nadi-D	1,100	50	1,500	-2.50	4.248	0.467	4.715	8.48E-04	496.008	86.99	5.50	5.70	0.03	1.00	3.02	0.40
Nadi-D	1,150	50	1,500	-2.50	4.298	0.459	4.757	8.26E-04	500.363	87.19	5.53	5.74	0.03	1.00	3.00	0.40
Nadi-D	1,200	50	1,500	-2.50	4.347	0.451	4.798	8.06E-04	504.587	87.39	5.57	5.77	0.03	1.00	2.97	0.40
Nadi-D	1,250	50	1,500	-2.50	4.394	0.444	4.838	7.87E-04	508.691	87.58	5.60	5.81	0.03	1.00	2.95	0.39
Nadi-D	1,300	50	1,500	-2.50	4.440	0.437	4.876	7.69E-04	512.720	87.76	5.63	5.84	0.03	1.00	2.93	0.39
Nadi-D	1,350	50	1,500	-2.50	4.484	0.430	4.914	7.52E-04	516.646	87.94	5.66	5.88	0.03	1.00	2.90	0.38
Nadi-D	1,400	50	1,500	-2.50	4.528	0.424	4.952	7.35E-04	520.473	88.11	5.69	5.91	0.03	1.00	2.88	0.38
Nadi-D	1,450	50	1,500	-2.50	4.570	0.418	4.988	7.20E-04	524.204	88.28	5.72	5.94	0.03	1.00	2.85	0.38
Nadi-D	1,500	50	1,500	-2.50	4.612	0.412	5.024	7.06E-04	527.857	88.45	5.75	5.97	0.03	1.00	2.84	0.37
Nadi-D	1,550	50	1,500	-2.50	4.652	0.406	5.059	6.92E-04	531.452	88.61	5.78	6.00	0.03	1.00	2.82	0.37
Nadi-D	1,600	50	1,500	-2.50	4.692	0.401	5.093	6.78E-04	534.966	88.77	5.80	6.03	0.03	1.00	2.80	0.36
Nadi-D	1,650	50	1,500	-2.50	4.730	0.396	5.126	6.66E-04	538.403	88.92	5.83	6.05	0.03	1.00	2.79	0.36
Nadi-D	1,700	50	1,500	-2.50	4.768	0.391	5.159	6.54E-04	541.766	89.07	5.86	6.08	0.03	1.00	2.77	0.36
Nadi-D	1,750	50	1,500	-2.50	4.805	0.386	5.192	6.42E-04	545.065	89.22	5.88	6.11	0.03	1.00	2.75	0.36
Nadi-D	1,800	50	1,500	-2.50	4.842	0.382	5.224	6.31E-04	548.327	89.37	5.91	6.14	0.03	1.00	2.74	0.35
Nadi-D	1,850	50	1,500	-2.50	4.878	0.377	5.255	6.20E-04	551.525	89.51	5.93	6.16	0.03	1.00	2.72	0.35
Nadi-D	1,900	50	1,500	-2.50	4.913	0.373	5.286	6.10E-04	554.661	89.65	5.95	6.19	0.03	1.00	2.70	0.35
Nadi-D	1,950	50	1,500	-2.50	4.947	0.369	5.316	6.00E-04	557.740	89.79	5.98	6.21	0.03	1.00	2.69	0.34
Nadi-D	2,000	50	1,500	-2.50	4.981	0.365	5.346	5.91E-04	560.762	89.92	6.00	6.24	0.03	1.00	2.67	0.34
Nadi-D	2,050	50	1,500	-2.50	5.014	0.361	5.375	5.82E-04	563.743	90.05	6.02	6.26	0.03	1.00	2.66	0.34
Nadi-D	2,100	50	1,500	-2.50	5.046	0.357	5.404	5.73E-04	566.690	90.19	6.04	6.28	0.03	1.00	2.65	0.34
Nadi-D	2,150	50	1,500	-2.50	5.078	0.354	5.432	5.64E-04	569.587	90.31	6.07	6.31	0.03	1.00	2.63	0.33
Nadi-D	2,200	50	1,500	-2.50	5.110	0.350	5.460	5.56E-04	572.436	90.44	6.09	6.33	0.03	1.00	2.62	0.33
Nadi-D	2,250	50	1,500	-2.50	5.141	0.347	5.488	5.48E-04	575.238	90.56	6.11	6.35	0.03	1.00	2.61	0.33
Nadi-D	2,300	50	1,500	-2.50	5.171	0.344	5.515	5.40E-04	577.997	90.69	6.13	6.37	0.03	1.00	2.60	0.33
Nadi-D	2,350	50	1,500	-2.50	5.201	0.340	5.542	5.33E-04	580.713	90.81	6.15	6.40	0.03	1.00	2.58	0.33
Nadi-D	2,400	50	1,500	-2.50	5.231	0.337	5.568	5.26E-04	583.414	90.92	6.17	6.42	0.03	1.00	2.57	0.32
Nadi-D	2,450	50	1,500	-2.50	5.260	0.334	5.594	5.19E-04	586.074	91.04	6.19	6.44	0.03	1.00	2.56	0.32
Nadi-D	2,500	50	1,500	-2.50	5.289	0.331	5.620	5.12E-04	588.696	91.16	6.21	6.46	0.03	1.00	2.55	0.32
Nadi-D	2,550	50	1,500	-2.34	5.300	0.347	5.647	5.48E-04	575.131	90.56	6.11	6.35	0.03	1.00	2.61	0.33
Nadi-D	2,600	50	1,500	-2.19	5.313	0.362	5.675	5.85E-04	562.750	90.01	6.02	6.25	0.03	1.00	2.67	0.34
Nadi-D	2,650	50	1,500	-2.03	5.325	0.380	5.705	6.27E-04	549.528	89.42	5.92	6.15	0.03	1.00	2.73	0.35
Nadi-D	2,700	50	1,500	-1.88	5.340	0.397	5.738	6.69E-04	537.508	88.88	5.82	6.05	0.03	1.00	2.79	0.36
Nadi-D	2,750	50	1,500	-1.72	5.355	0.417	5.772	7.18E-04	524.658	88.30	5.72	5.94	0.03	1.00	2.86	0.37
Nadi-D	2,800	50	1,500	-1.56	5.372	0.438	5.810	7.72E-04	512.015	87.73	5.63	5.84	0.03	1.00	2.93	0.39
Nadi-D	2,850	50	1,500	-1.41	5.392	0.458	5.850	8.25E-04	500.616	87.21	5.54	5.74	0.03	1.00	3.00	0.40
Nadi-D	2,900	50	1,500	-1.25	5.411	0.481	5.892	8.87E-04	488.416	86.64	5.44	5.64	0.03	1.00	3.07	0.41
Nadi-D	2,950	50	1,500	-1.09	5.433	0.506	5.938	9.55E-04	476.472	86.09	5.34	5.53	0.03	1.00	3.15	0.43
Nadi-D	3,000	50	1,500	-0.94	5.459	0.529	5.988	1.02E-03	465.836	85.60	5.26	5.44	0.03	1.00	3.22	0.44
Nadi-D	3,050	50	1,500	-0.78	5.336	0.702	6.038	9.88E-04	404.376	72.23	5.07	5.60	0.03	1.00	3.71	0.50
Nadi-D	3,100	50	1,500	-0.63	5.353	0.737	6.089	1.06E-03	394.760	71.97	4.92	5.49	0.03	1.00	3.80	0.52
Nadi-D	3,150	50	1,500	-0.47	5.368	0.777	6.145	1.15E-03	384.337	71.68	4.87	5.36	0.03	1.00	3.90	0.54
Nadi-D	3,200	50	1,500	-0.31	5.144	1.072	6.216	1.71E-03	327.265	60.00	4.62	5.45	0.03	1.00	4.58	0.63
Nadi-D	3,250	50	1,500	-0.16	5.190	1.114	6.304	1.81E-03	321.027	60.00	4.54	5.35	0.03	1.00	4.67	0.65
Nadi-D	3,300	50	1,500	0.00	5.235	1.164	6.398	1.94E-03	314.072	60.00	4.46	5.23	0.03	1.00	4.78	0.67

dx: distance
Q: discharge
H bed: elevation of river bed
H: water level
V.H: velocity head
total E: total energy head
IE: energy gradient
A: discharge area
B: width of water surface
R: hydraulic radius
A/B: hydraulic depth
n: roughness coefficient
alpha: energy correction coefficient
V: velocity
Fr: Froude number

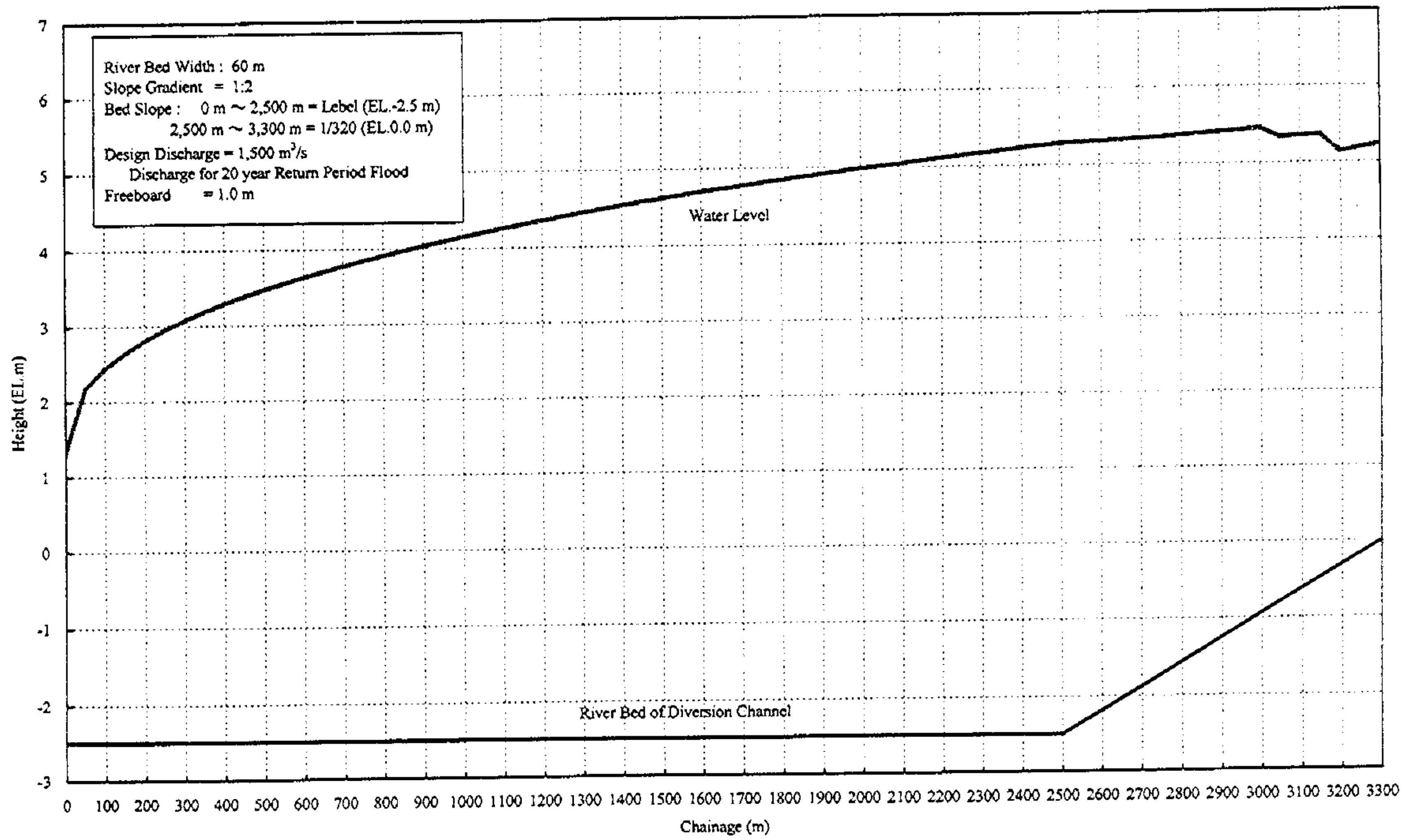


Figure-E11.6 Longitudinal Profile of Nadi Diversion Channel with Expected Water Level

11.4 Other Factors Considered

(1) Bank Erosion

When the design flood or 3 smaller floods (1/20, 1/15, 1/10 and 1/5 probability floods) flows in the diversion channel, the maximum velocity of flow would be approximately 5 m/sec, regardless of flood size. Therefore, bank protection works, such as vegetation, are required.

According to the analysis conducted in this study, there is no critical areas of water collision, except diverting point. Therefore, revetment works are considered not necessary at this stage of study. However, results of hydraulic model experiment recommended for the next stage (detail design stage) may require revetment works and bed protection works. In the structural design (Chapter 12), water collision prone area which is left bank of the diversion channel at a bend is designed to have more strength than other areas of bank by widening bank width. Therefore, if bank protection for critical areas of water collision was required in the further study, it would be recommended to consider not only revetment works but also increase in bank stability by widening bank width and applying more gentle bank slope.

(2) Sedimentation in Diversion Channel and Nadi River

Since bed elevation of the diversion channel is 1.0 m higher than that of Nadi river at diverting point, bed load flows only in Nadi river but not in the diversion channel. Therefore, only suspended load flows and some may be deposited in the diversion channel. Since the suspended load mostly consists of particles smaller than 0.03 cm, its deposit is easily drained by a flush of flood (see Supporting Report Part I).

Bed load deposit in a particular place of Nadi river is not expected, because weir structures are not planned. Even if there is some change in river profile, dynamic equilibrium gradient will be achieved soon, and scouring and sediment deposit in a particular place is not expected.

(3) Sedimentation at Outlet

Since there is no flow, except periodical tidal flow, in the diversion channel for 75 % of year, sea sand is expected to be deposited at the outlet of the diversion channel. However, particle size of sand in the Nadi bay is fine enough to be flushed by drainage of floods. Therefore, the cross section of the diversion channel is maintained.

In Supporting Report Part I, Coastal Investigation, sediment transportation through the diversion channel was studied based on the hydrograph of flood and particle size distribution in the upper reach of Nadi river. The study results show that sediment load through the diversion channel mostly consists of particles smaller than fine sand ($\leq$ 0.03 cm), such as suspended load and wash load. Those particles are easily drained into the sea and diffused by ordinal tide. Therefore, serious problems of sedimentation at outlet are not expected to occur.

Present conditions at outlet of the Sabeto drainage canal located near the diversion channel site prove the above. Although there are flood gates at outlet resulting in rapid decline of flow velocity, sedimentation at outlet is hardly observed.

Sediment load through the diversion channel is considered not to cause serious problems at outlet. However, it is recommended to conduct sediment transportation experiment to review the sediment transportation and study sedimentation in the Nadi bay in details if the project proceeds the next stage, detailed design stage.

(4) Storm Surge

The study on extension of the Nadi airport assumed that storm surge of 20 year return period is EL. 3.0 m. Since the historical records has not confirmed that figure, it may be overestimate; however, it is considered as a safety factor for the airport extension.

Assuming that sea level is EL. 3.0 m and discharge of the diversion channel is 1,500 m^3/sec (drainage for 20 year return period flood), water level of the diversion channel was calculated and results are shown in Table-E11.6 and Figure-E11.7. As shown in Figure-E11.7, water level when sea level is EL. 3.0 m is within freeboard at any section of the diversion channel. Therefore, even if storm surge was EL. 3.0 m, the diversion channel would drain the deign discharge safely.

(5) Flood Gate

Sugarcane is currently cultivated along the proposed alignment of the diversion channel; however, its area is expected to be reduced considerably due to the future land use, such as the extension project of Nadi airport, tourism development and earth works of the diversion channel. Since the diversion channel project proposes land development of soil disposal area, it would stipulate the development in the vicinity of the diversion channel resulting in the further reduction of sugarcane field if the proposal was implemented. Therefore, flood gates at outlet of the diversion channel are considered not necessary because there will be no crops to be protected from saline problems.

Flood gates at outlet induce water stagnation resulting in water pollution. The direct results may be mosquito breeding, emitting of unpleasant smell or odor, and unwanted growth of vegetation in the channel. This problem has been pointed out by many specialists and thought to be hazardous to public health in the surrounding area. Therefore, flood gates are not recommendable from an environmental point of view.

Sea water intrusion through the diversion channel is discussed in the next section. Conclusion is that the sea water hardly reach to Nadi river through the channel. Since sea water intrusion improves water quality in the channel by periodical flow of tide and hardly affect water quality of Nadi river through the channel, flood gates should not be installed.

Flood gates are considered not necessary at this stage of the study. Necessity of flood gates to mitigate saline problems should be examined by groundwater monitoring along the site of the diversion channel after completion of the diversion channel construction.

Table-E11.6 Estimate of Storm Surge Effect

Name		dX (m)	Q (m^3/s)	H bed (m)	H (m)	V.H (m)	total E (m)	IE	A (m^2)	B (m)	R (m)	A/B (m)	n	alpha	V (m/s)	Fr
Nadi-D	-1,500	0	1,500	-5.50	3.000	0.004	3.004	4.66E-06	5,100.000	600.00	8.27	8.50	0.03	1.00	0.29	0.03
Nadi-D	-1,000	500	1,500	-4.50	2.998	0.012	3.009	1.46E-05	3,149.008	420.00	7.24	7.50	0.03	1.00	0.48	0.06
Nadi-D	-500	500	1,500	-3.50	2.984	0.047	3.031	7.42E-05	1,556.161	240.00	6.15	6.48	0.03	1.00	0.96	0.12
Nadi-D	-450	50	1,500	-3.40	2.978	0.057	3.036	9.20E-05	1,415.984	222.00	6.03	6.38	0.03	1.00	1.06	0.13
Nadi-D	-400	50	1,500	-3.30	2.971	0.070	3.041	1.16E-04	1,279.203	204.00	5.91	6.27	0.03	1.00	1.17	0.15
Nadi-D	-350	50	1,500	-3.20	2.960	0.087	3.047	1.49E-04	1,145.745	186.00	5.78	6.16	0.03	1.00	1.31	0.17
Nadi-D	-300	50	1,500	-3.10	2.945	0.111	3.056	1.96E-04	1,015.504	168.00	5.64	6.04	0.03	1.00	1.48	0.19
Nadi-D	-250	50	1,500	-3.00	2.922	0.145	3.068	2.65E-04	888.303	150.00	5.49	5.92	0.03	1.00	1.69	0.22
Nadi-D	-200	50	1,500	-2.90	2.887	0.197	3.083	3.74E-04	763.847	132.00	5.32	5.79	0.03	1.00	1.96	0.26
Nadi-D	-150	50	1,500	-2.80	2.828	0.279	3.107	5.57E-04	641.575	114.00	5.12	5.63	0.03	1.00	2.34	0.31
Nadi-D	-100	50	1,500	-2.70	2.719	0.424	3.143	9.07E-04	520.241	96.00	4.87	5.42	0.03	1.00	2.88	0.40
Nadi-D	-50	50	1,500	-2.60	2.478	0.732	3.210	1.74E-03	396.061	78.00	4.49	5.08	0.03	1.00	3.79	0.54
Nadi-D	0	50	1,500	-2.50	2.289	1.034	3.323	2.79E-03	333.213	79.16	4.09	4.21	0.03	1.00	4.50	0.70
Nadi-D	50	50	1,500	-2.50	2.525	0.926	3.451	2.36E-03	352.019	80.10	4.27	4.39	0.03	1.00	4.26	0.65
Nadi-D	100	50	1,500	-2.50	2.710	0.853	3.562	2.08E-03	366.877	80.84	4.40	4.54	0.03	1.00	4.09	0.61
Nadi-D	150	50	1,500	-2.50	2.864	0.797	3.662	1.88E-03	379.426	81.46	4.52	4.66	0.03	1.00	3.95	0.59
Nadi-D	200	50	1,500	-2.50	2.999	0.753	3.752	1.73E-03	390.404	82.00	4.62	4.76	0.03	1.00	3.84	0.56
Nadi-D	250	50	1,500	-2.50	3.119	0.716	3.835	1.60E-03	400.300	82.48	4.70	4.85	0.03	1.00	3.75	0.54
Nadi-D	300	50	1,500	-2.50	3.228	0.685	3.913	1.50E-03	409.282	82.91	4.78	4.94	0.03	1.00	3.66	0.53
Nadi-D	350	50	1,500	-2.50	3.328	0.658	3.986	1.41E-03	417.591	83.31	4.85	5.01	0.03	1.00	3.59	0.51
Nadi-D	400	50	1,500	-2.50	3.420	0.635	4.055	1.34E-03	425.300	83.68	4.92	5.08	0.03	1.00	3.53	0.50
Nadi-D	450	50	1,500	-2.50	3.506	0.614	4.120	1.27E-03	432.557	84.03	4.98	5.15	0.03	1.00	3.47	0.49
Nadi-D	500	50	1,500	-2.50	3.587	0.595	4.182	1.21E-03	439.366	84.35	5.04	5.21	0.03	1.00	3.41	0.48
Nadi-D	550	50	1,500	-2.50	3.664	0.577	4.242	1.16E-03	445.854	84.66	5.09	5.27	0.03	1.00	3.36	0.47
Nadi-D	600	50	1,500	-2.50	3.737	0.562	4.299	1.12E-03	452.012	84.95	5.14	5.32	0.03	1.00	3.32	0.46
Nadi-D	650	50	1,500	-2.50	3.806	0.548	4.353	1.07E-03	457.874	85.22	5.19	5.37	0.03	1.00	3.28	0.45
Nadi-D	700	50	1,500	-2.50	3.872	0.534	4.406	1.04E-03	463.527	85.49	5.24	5.42	0.03	1.00	3.24	0.44
Nadi-D	750	50	1,500	-2.50	3.935	0.522	4.457	1.00E-03	468.936	85.74	5.28	5.47	0.03	1.00	3.20	0.44
Nadi-D	800	50	1,500	-2.50	3.996	0.511	4.506	9.69E-04	474.124	85.98	5.32	5.51	0.03	1.00	3.16	0.43
Nadi-D	850	50	1,500	-2.50	4.054	0.500	4.554	9.39E-04	479.166	86.22	5.36	5.56	0.03	1.00	3.13	0.42
Nadi-D	900	50	1,500	-2.50	4.110	0.490	4.600	9.11E-04	484.026	86.44	5.40	5.60	0.03	1.00	3.10	0.42
Nadi-D	950	50	1,500	-2.50	4.165	0.481	4.645	8.86E-04	488.717	86.66	5.44	5.64	0.03	1.00	3.07	0.41
Nadi-D	1,000	50	1,500	-2.50	4.217	0.472	4.689	8.62E-04	493.268	86.87	5.48	5.68	0.03	1.00	3.04	0.41
Nadi-D	1,050	50	1,500	-2.50	4.268	0.463	4.731	8.39E-04	497.707	87.07	5.51	5.72	0.03	1.00	3.01	0.40
Nadi-D	1,100	50	1,500	-2.50	4.317	0.456	4.773	8.18E-04	502.009	87.27	5.55	5.75	0.03	1.00	2.99	0.40
Nadi-D	1,150	50	1,500	-2.50	4.365	0.448	4.813	7.98E-04	506.186	87.46	5.58	5.79	0.03	1.00	2.96	0.39
Nadi-D	1,200	50	1,500	-2.50	4.412	0.441	4.853	7.80E-04	510.257	87.65	5.61	5.82	0.03	1.00	2.94	0.39
Nadi-D	1,250	50	1,500	-2.50	4.457	0.434	4.891	7.62E-04	514.248	87.83	5.64	5.86	0.03	1.00	2.92	0.39
Nadi-D	1,300	50	1,500	-2.50	4.501	0.428	4.929	7.45E-04	518.135	88.01	5.67	5.89	0.03	1.00	2.89	0.38
Nadi-D	1,350	50	1,500	-2.50	4.544	0.421	4.966	7.29E-04	521.924	88.18	5.70	5.92	0.03	1.00	2.87	0.38
Nadi-D	1,400	50	1,500	-2.50	4.586	0.416	5.002	7.14E-04	525.621	88.35	5.73	5.95	0.03	1.00	2.85	0.37
Nadi-D	1,450	50	1,500	-2.50	4.627	0.410	5.037	7.00E-04	529.255	88.51	5.76	5.98	0.03	1.00	2.83	0.37
Nadi-D	1,500	50	1,500	-2.50	4.668	0.404	5.072	6.86E-04	532.818	88.67	5.79	6.01	0.03	1.00	2.82	0.37
Nadi-D	1,550	50	1,500	-2.50	4.707	0.399	5.106	6.73E-04	536.302	88.83	5.81	6.04	0.03	1.00	2.80	0.36
Nadi-D	1,600	50	1,500	-2.50	4.745	0.394	5.139	6.61E-04	539.709	88.98	5.84	6.07	0.03	1.00	2.78	0.36
Nadi-D	1,650	50	1,500	-2.50	4.783	0.389	5.172	6.49E-04	543.046	89.13	5.87	6.09	0.03	1.00	2.76	0.36
Nadi-D	1,700	50	1,500	-2.50	4.820	0.385	5.204	6.38E-04	546.332	89.28	5.89	6.12	0.03	1.00	2.75	0.35
Nadi-D	1,750	50	1,500	-2.50	4.856	0.380	5.236	6.27E-04	549.569	89.42	5.92	6.15	0.03	1.00	2.73	0.35
Nadi-D	1,800	50	1,500	-2.50	4.891	0.376	5.267	6.16E-04	552.743	89.56	5.94	6.17	0.03	1.00	2.71	0.35
Nadi-D	1,850	50	1,500	-2.50	4.926	0.372	5.297	6.06E-04	555.857	89.70	5.96	6.20	0.03	1.00	2.70	0.35
Nadi-D	1,900	50	1,500	-2.50	4.960	0.367	5.327	5.96E-04	558.913	89.84	5.99	6.22	0.03	1.00	2.68	0.34
Nadi-D	1,950	50	1,500	-2.50	4.993	0.364	5.357	5.87E-04	561.914	89.97	6.01	6.25	0.03	1.00	2.67	0.34
Nadi-D	2,000	50	1,500	-2.50	5.026	0.360	5.386	5.78E-04	564.887	90.11	6.03	6.27	0.03	1.00	2.66	0.34
Nadi-D	2,050	50	1,500	-2.50	5.059	0.356	5.415	5.69E-04	567.815	90.24	6.05	6.29	0.03	1.00	2.64	0.34
Nadi-D	2,100	50	1,500	-2.50	5.091	0.352	5.443	5.61E-04	570.693	90.36	6.07	6.32	0.03	1.00	2.63	0.33
Nadi-D	2,150	50	1,500	-2.50	5.122	0.349	5.471	5.53E-04	573.523	90.49	6.10	6.34	0.03	1.00	2.62	0.33
Nadi-D	2,200	50	1,500	-2.50	5.153	0.346	5.498	5.45E-04	576.308	90.61	6.12	6.36	0.03	1.00	2.60	0.33
Nadi-D	2,250	50	1,500	-2.50	5.183	0.342	5.525	5.38E-04	579.050	90.73	6.14	6.38	0.03	1.00	2.59	0.33
Nadi-D	2,300	50	1,500	-2.50	5.213	0.339	5.552	5.30E-04	581.761	90.85	6.16	6.40	0.03	1.00	2.58	0.33
Nadi-D	2,350	50	1,500	-2.50	5.242	0.336	5.578	5.23E-04	584.445	90.97	6.18	6.42	0.03	1.00	2.57	0.32
Nadi-D	2,400	50	1,500	-2.50	5.271	0.333	5.604	5.16E-04	587.091	91.09	6.20	6.45	0.03	1.00	2.55	0.32
Nadi-D	2,450	50	1,500	-2.50	5.300	0.330	5.630	5.10E-04	589.698	91.20	6.21	6.47	0.03	1.00	2.54	0.32
Nadi-D	2,500	50	1,500	-2.50	5.328	0.327	5.655	5.03E-04	592.267	91.31	6.23	6.49	0.03	1.00	2.53	0.32
Nadi-D	2,550	50	1,500	-2.34	5.339	0.343	5.681	5.39E-04	578.656	90.71	6.13	6.38	0.03	1.00	2.59	0.33
Nadi-D	2,600	50	1,500	-2.19	5.351	0.358	5.709	5.74E-04	566.227	90.16	6.04	6.28	0.03	1.00	2.65	0.34
Nadi-D	2,650	50	1,500	-2.03	5.364	0.375	5.739	6.15E-04	552.954	89.57	5.94	6.17	0.03	1.00	2.71	0.35
Nadi-D	2,700	50	1,500	-1.88	5.378	0.392	5.771	6.57E-04	540.880	89.03	5.85	6.08	0.03	1.00	2.77	0.36
Nadi-D	2,750	50	1,500	-1.72	5.393	0.412	5.805	7.05E-04	527.974	88.45	5.75	5.97	0.03	1.00	2.84	0.37
Nadi-D	2,800	50	1,500	-1.56	5.409	0.432	5.841	7.58E-04	515.282	87.88	5.65	5.86	0.03	1.00	2.91	0.38
Nadi-D	2,850	50	1,500	-1.41	5.428	0.452	5.881	8.09E-04	503.837	87.35	5.56	5.77	0.03	1.00	2.98	0.40
Nadi-D	2,900	50	1,500	-1.25	5.448	0.475	5.923	8.71E-04	491.580	86.79	5.46	5.66	0.03	1.00	3.05	0.41
Nadi-D	2,950	50	1,500	-1.09	5.469	0.499	5.968	9.37E-04	479.565	86.23	5.37	5.56	0.03	1.00	3.13	0.42
Nadi-D	3,000	50	1,500	-0.94	5.494	0.522	6.016	1.00E-03	468.852	85.74	5.28	5.47	0.03	1.00	3.20	0.44
Nadi-D	3,050	50	1,500	-0.78	5.372	0.693	6.065	9.69E-04	407.007	72.30	5.09	5.63	0.03	1.00	3.69	0.50
Nadi-D	3,100	50	1,500	-0.63	5.389	0.727	6.116	1.04E-03	397.345	72.04	5.00	5.52	0.03	1.00	3.78	0.51
Nadi-D	3,150	50	1,500	-0.47	5.403	0.767	6.170	1.13E-03	386.877	71.75	4.90	5.39	0.03	1.00	3.89	0.53
Nadi-D	3,200	50	1,500	-0.31	5.183	1.057	6.240	1.67E-03	329.602	60.00	4.64	5.49	0.03	1.00	4.55	0.62
Nadi-D	3,250	50	1,500	-0.16	5.228	1.099	6.326	1.78E-03	323.261	60.00	4.57	5.39	0.03	1.00	4.64	0.64
Nadi-D	3,300	50	1,500	0.00	5.270	1.148	6.418	1.90E-03	316.204	60.00	4.48	5.27	0.03	1.00	4.74	0.66

dx: distance
V.H: velocity head
B: width of water surface
alpha: energy correction coefficient
Q: discharge
total E: total energy head
R: hydraulic radius
V: velocity
H bed: elevation of river bed
IE: energy gradient
A/B: hydraulic depth
Fr: Froude number
H: water level
A: discharge area
n: roughness coefficient

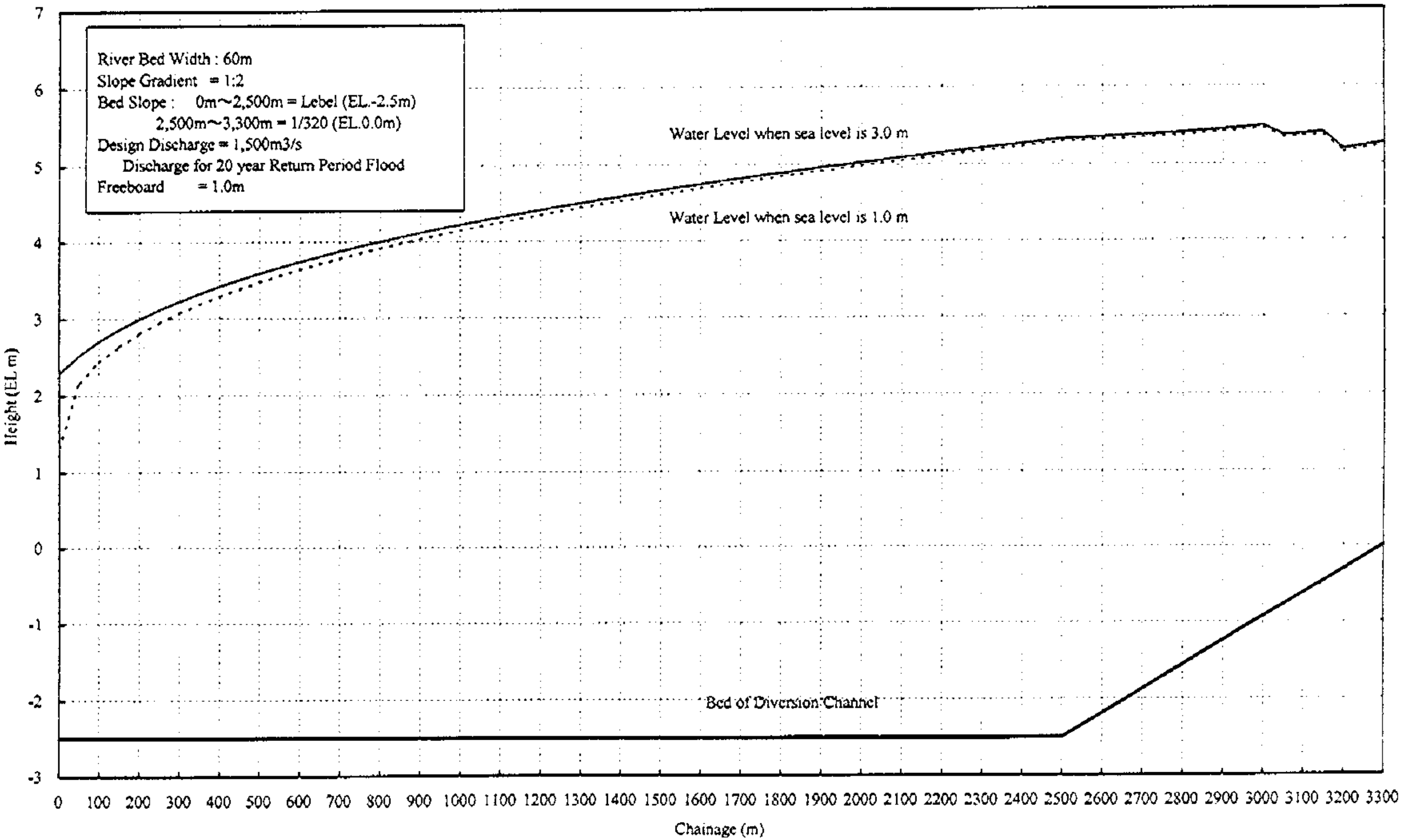


Figure-E11.7 Expected Water Level by Storm Surge

(6) Sea Water Intrusion

When the brine intrudes into river, saltwater wedge is formed due to the difference of specific gravity between the fresh water and brine as shown in Figure-E11.8.

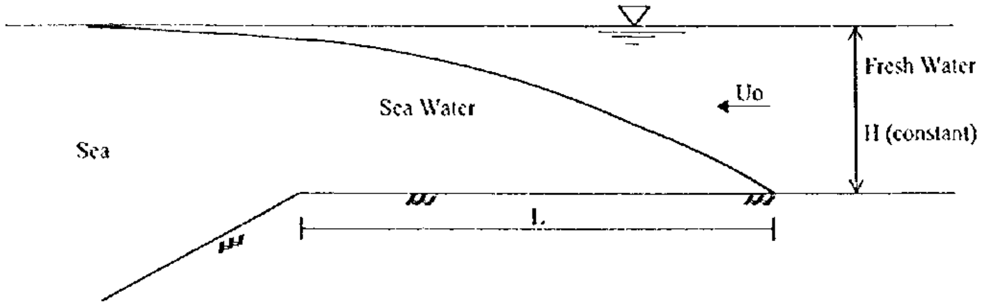


Figure-E11.8 Saltwater Wedge

Since the diversion channel bed is designed to be flat from downstream end to 2,500 m point and is raised from 2,500 m point to inlet, saltwater wedge is difficult to move on further upstream as shown in Figure-E11.9.

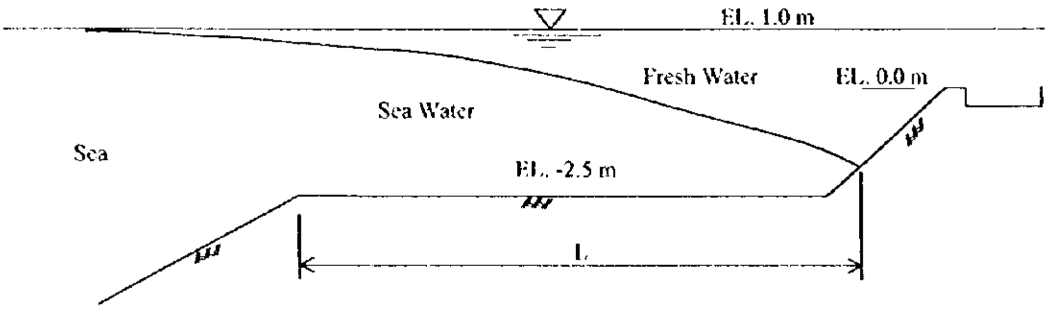


Figure-E11.9 Saltwater Wedge (Diversion Channel)

Based on the following equation (Schijf et al., 1953, and Harleman, 1961), effective length of saltwater wedge was estimated.

$$L = \frac{H}{2\bar{f}_i} \left(\frac{1}{5} F_{do}^{-2} - 2 + 3F_{do}^{2/3} - \frac{6}{5} F_{do}^{4/3} \right)$$

$$F_{do} = \frac{U_0}{\sqrt{gH}} = 0.04 \sim 0.05$$

$$\bar{f}_i = 0.01$$

where, U_0 : velocity of fresh water

H : water depth

g : acceleration of gravity

L : effective length of saltwater wedge

As a result, the effective length of saltwater wedge (L) is approximately 2,000 m ~ 3,100 m. Since total length of the diversion channel is 3,300 m, sea water intrusion is not expected to reach Nadi river through the channel.

Literature Cited

Harleman, D.R.F. (1961). "Handbook of Fluid Dynamics", Mc-Graw-Hill, p.21.

Schijf, J.B. and Schonfeld, J.C. (1953). "Theoretical consideration of the motion of salt and fresh water." Proc, Minnesota Int. Hyd. Conf., pp. 321~333.

CHAPTER 12 STRUCTURAL DESIGN

12.1 Design Standards in Fiji

Since there is no design standards in Fiji, all civil works are designed by adopting other countries' standards. For example, roads are designed based on the Australian standards, while large scale bridges, such as Ba and Sigatoka bridges constructed recently, are designed based on the New Zealand standards. structural

Fiji does not have any experience to design a large scale channel such as the diversion channel proposed in the Study, while irrigation and drainage channels with small scale are designed based on the Australian standards as a rule. In most of cases, however, they are designed based on previous works. For example, slope of embankment is determined in accordance with existing banks.

12.2 Objective Structures for Feasibility Study

Feasibility Study of the Nadi diversion channel and short cut channel includes the following structures based on the hydraulic design and current landuse in the vicinity of site. Structural design was examined for the design flood (20 year return period flood). Based on the results of examination, structural designs for smaller floods (1/15, 1/10 and 1/5 probability floods) were determined by changing bed width.

1) Diversion channel
2) Short cut channel
3) Bridges for vehicles, sugarcane tramline and pedestrians
4) Road
5) Others (replacement)
   sugarcane tramline, water and sewage pipe lines, electric cable and telephone line

12.3 Design of Diversion Channel

12.3.1 Alignment

As a result of the Master Plan Study, the alignment No.2 has been selected as the most feasible route of the Nadi diversion channel among the 4 alignments. Based on the alignment No.2, the specific route of the channel was determined considering the following conditions and the result is shown in Figure-E12.1.

1) Since there are residential and tourism development plans in the area on the north of site for the airport extension and on the east of Enamanu road, this area should be avoided for the diversion channel.
2) A cemetery and transmitter station of the Nadi airport are located along the western side of Enamanu road between Queens road and site for the airport extension. Therefore, those area should be avoided for the diversion channel.
3) To locate the diversion channel in the airport extension site has been agreed by the Civil Aviation Authority of Fiji, as long as the diversion channel does not cross the area within 300 m from the end of planned runway.

4) There is a private cemetery in Waqadra garden on the east of Queens road and there is a traditional sacred site in the north of McDonald's and on the west of Queens road. Those areas should be avoided for the diversion channel.

5) Since compensation for McDonald's is expected very high, it should be avoided for the diversion channel.

12.3.2 Longitudinal Profile

No. 0 point of the topographical survey is located on a road along the seashore, while the starting point of hydraulic design is located 150 m offshore from the road where sea bed is almost same elevation as the diversion channel bed (EL. -2.5 m). Therefore, the total length of the diversion channel in the hydraulic design is counted from a point of 150 m offshore and is 3,300 m. In the structural design, distances are always referred to No. 0 point where outlet is to be located. As a result, the distance from outlet to inlet is 3,150 m.

Based on the hydraulic design, bed slope of the diversion channel was determined as flat from outlet to 2,350 m (EL. -2.5 m) and 1/320 from 2,350 m to inlet. As shown in Figure-E12.2, the longitudinal profile of the diversion channel has two sections, embankment and cutting sections. The former is located from outlet to 1,500 m and the latter is located from 1,500 m to inlet (3,150 m from outlet).

In the section of embankment, freeboard was designed to have at least 1.0 m from water level of the design discharge (1,500 m^3/sec, drainage for 1/20 probability flood), as shown in Figure-E12.2. Longitudinal slope of bank crest is 1/800.

12.3.3 Cross Section

Standard cross sections of the diversion channel based on the following conditions are shown in Figure-E12.3.

(1) Cutting Section

Slope gradient in the cutting section was determined as 1:2 based on the results of soil test conducted by the Study Team and design of existing structures. Since the deepest depth of cutting is 13 m, berm with 3 m width was designed at 5.0 m high from channel bed for maintenance of the channel.

Vegetation is applied on the bank slope to prevent bank erosion.

(2) Embankment Section

Slope gradient in the embankment section was determined as 1:3 based on the bank stability analysis discussed in the following section. Berm with 3 m width was also designed for maintenance and increase in bank stability (see the section 12.3.4).

The cross sections adopted in the structural design are slightly different from that assumed in the hydraulic design. As the area of the former cross section is almost same to or slightly larger than the latter, the difference does not cause any significant change in the hydraulic analysis.

Vegetation is applied on the bank slope to prevent bank erosion.

Since crest of bank is used for road whose size is same as Nasoso road, the crest width of bank was designed 8.0 m; however, it can be reduced to 4.0 m as long as only the bank stability is considered (Japanese Standards).

The left bank at a bend is considered as water collision prone area but not critical based on the hydraulic examination. There are two bends; however, one in the upper reach does not require any measure because it is located in the cutting section whose slope is stable. Another in the lower reach is located in the embankment section. Therefore, some measures should be considered in case of bank collapse. Since the disposal area for surplus soil is planned next to the bend, bank width inclusive of soil disposal area at the bend is much bigger than the other sections. As a result, bank stability is maintained by widening bank width and any revetment works are not required.

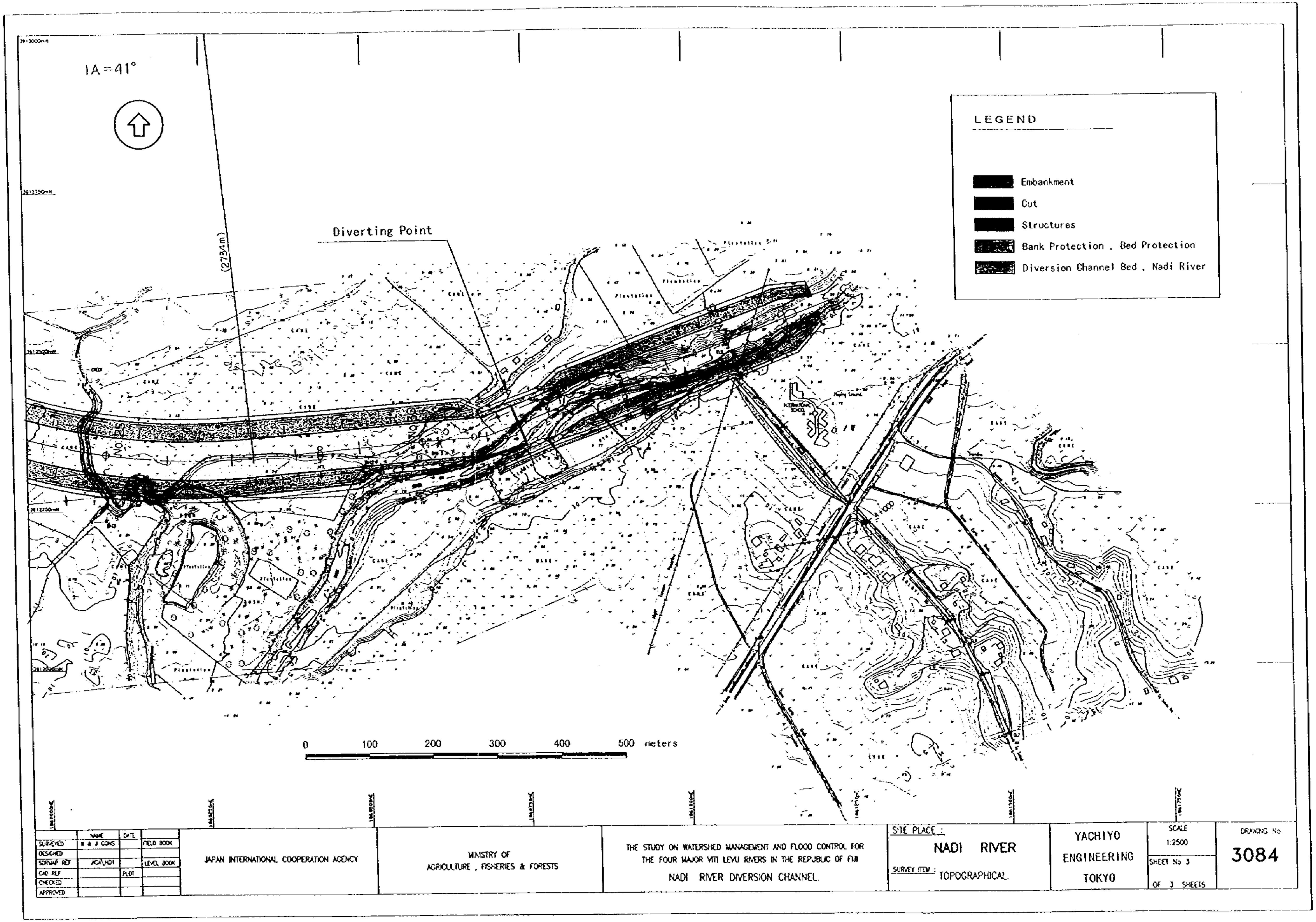


Figure-E12.1 (1/3) Plan of Diversion Channel for 20 Year Return Period Flood

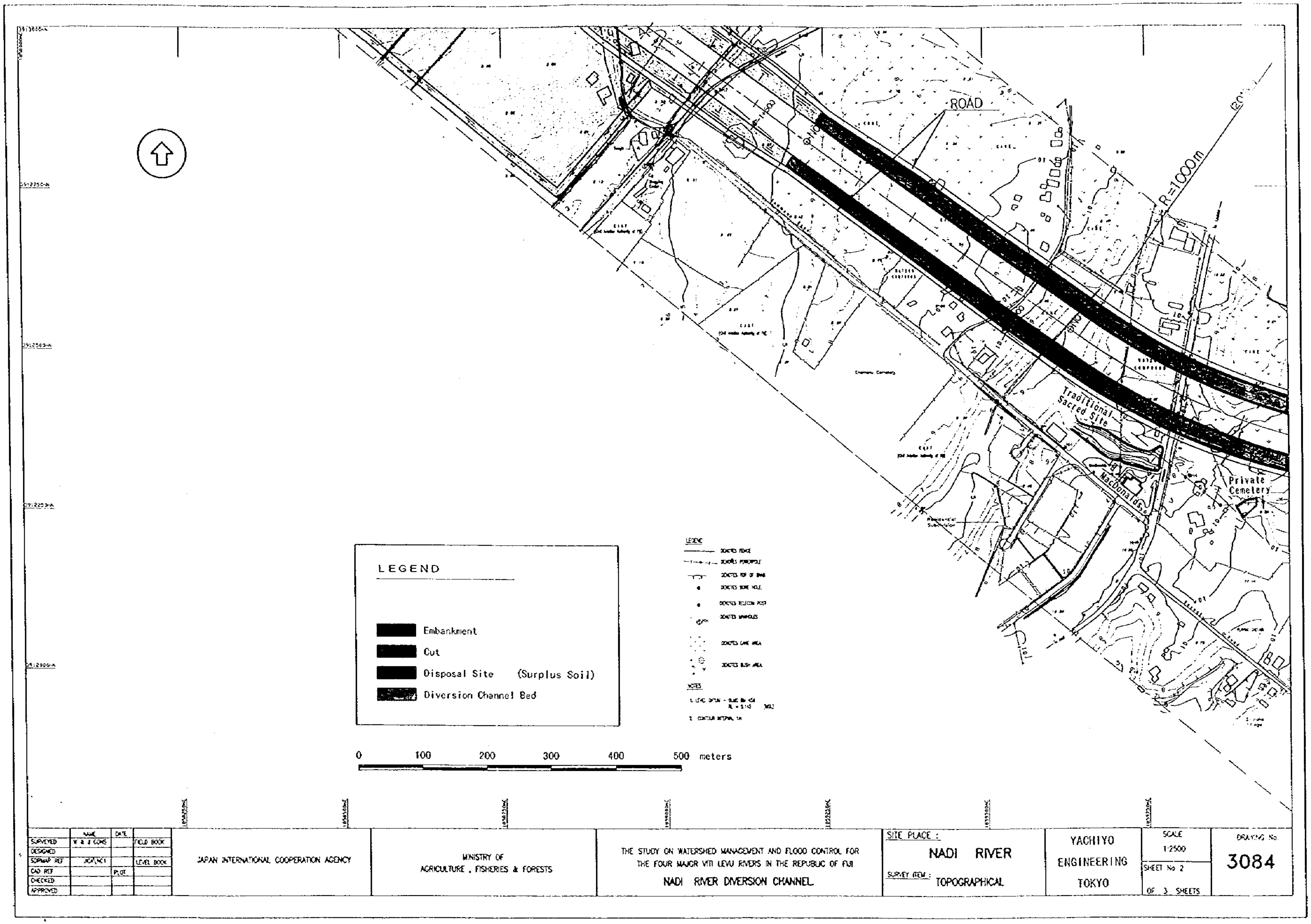


Figure-E12.1 (2/3) Plan of Diversion Channel for 20 Year Return Period Flood

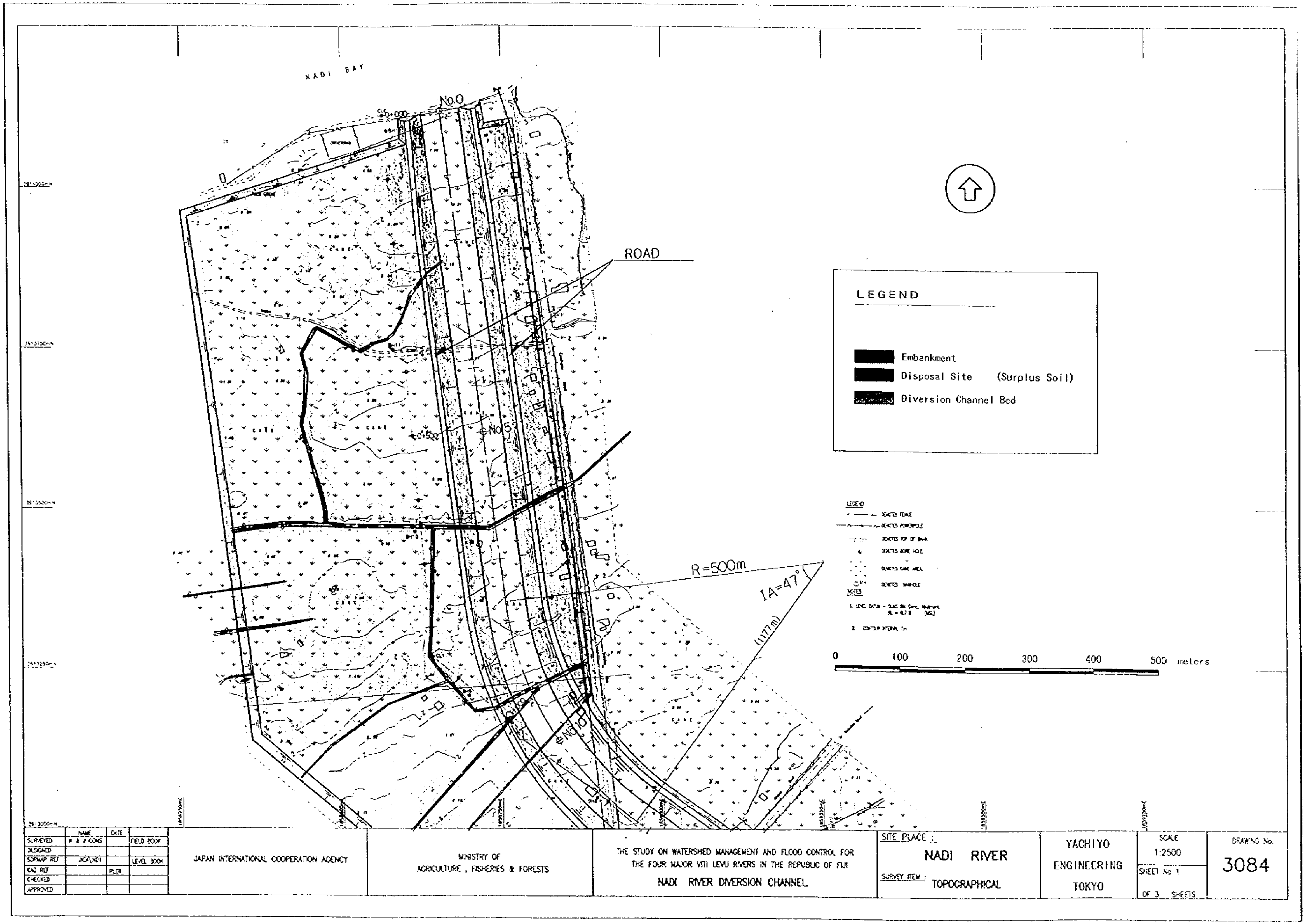
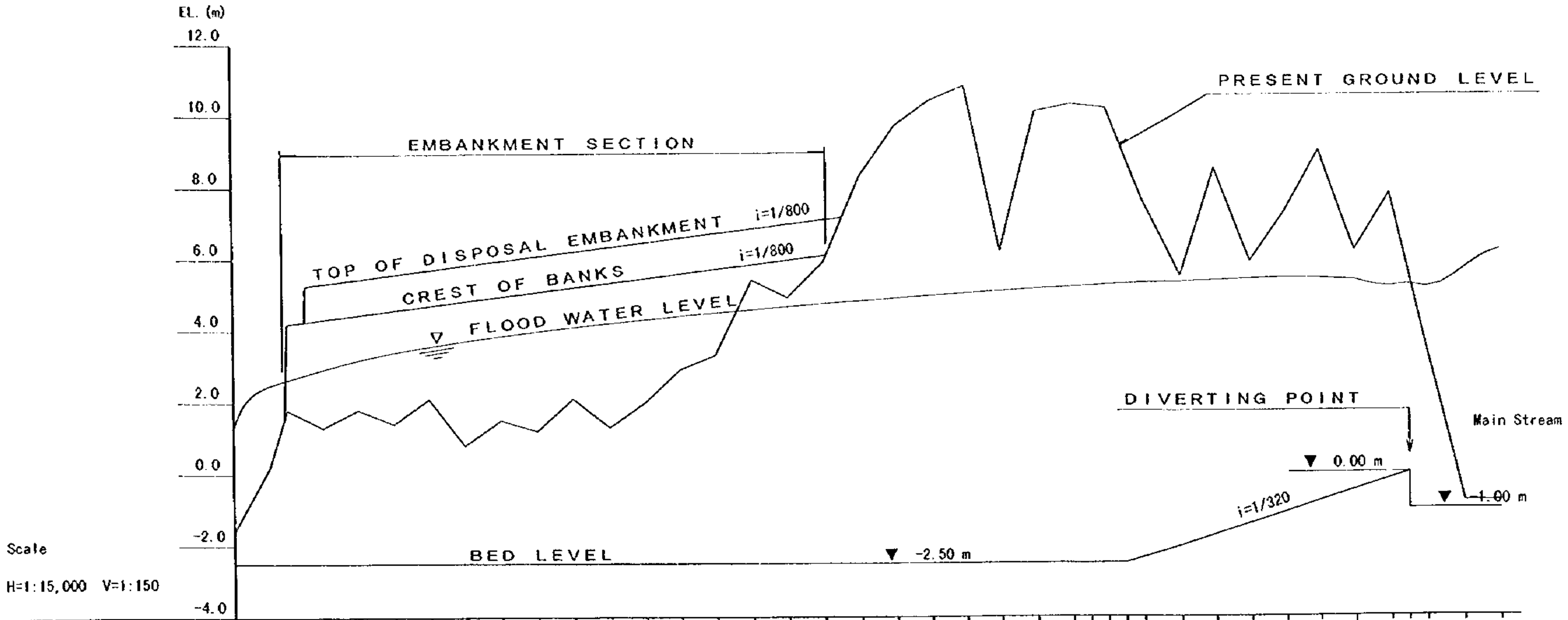


Figure-E12.1 (3/3) Plan of Diversion Channel for 20 Year Return Period Flood



STATION	DISTANCE (m)	PRESENT GROUND LEVEL (EL. m)	FLOOD LEVEL (EL. m)	BED LEVEL (EL. m)	CREST OF BANKS (EL. m)
No.0 -150	0.00	-1.6	1.32	-2.50	0.00
		0.2			0.00
NO.0	150	1.8	2.64		4.20
		1.3			
NO.2	350	1.8	3.19		4.45
		1.4			
NO.4	550	2.1	3.56		4.70
		0.8			
NO.6	750	1.5	3.85		4.95
		1.2			
NO.8	950	2.1	4.09		5.20
		1.3			
NO.10	1150	2.0	4.30		5.45
		2.9			
NO.12	1350	3.3	4.48		5.70
		5.4			
NO.14	1550	4.9	4.65		5.95
		5.9			
NO.16	1750	8.3	4.81		
		9.7			
NO.18	1950	10.4	4.95		
		10.8			
NO.20	2150	6.2	5.08		
		10.1			
NO.22	2350	10.3	5.20		
	2400				
		10.2			
	2500			-2.50	
NO.24	2550	7.6	5.30	-2.34	
	2650	5.5			
NO.26	2750	8.5	5.36	-1.72	
		5.9			
NO.28	2950	7.3	5.43	-1.09	
		9.0			
NO.30	3150	6.2	5.37	-0.47	
		7.8			
	3300			0.00	
NO.32	3350	3.4	5.163	-1.00	
		-0.8			
NO.34	3550	-0.8	6.202	-1.00	

Figure-E12.2 Longitudinal Profile of Diversion Channel for 20 Year Return Period Flood

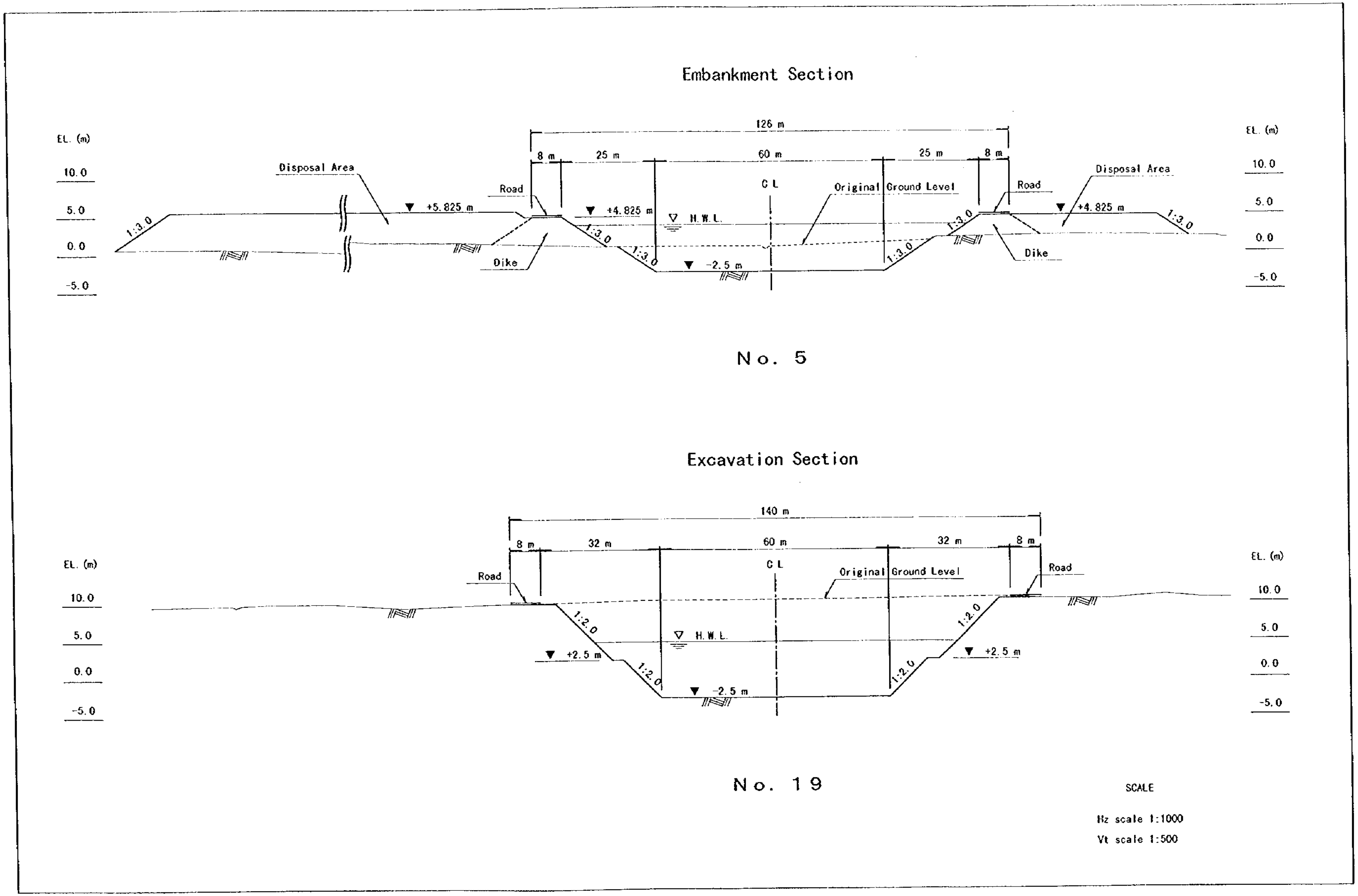


Figure-E12.3 Standard Cross Section of Diversion Channel for 20 Year Return Period Flood

12.3.4 Stability Analysis of Embankment

According to the geological survey and soil test conducted by the Study Team (Supporting Report Part B), loose and weak sand and clay deposits, especially Cwc (weak clay layer) and Cws (weak silt layer), are underlain around the designed bottom of the diversion channel in the lower reach, from outlet to 1,200 m. Effect of the loose and weak deposits on bank stability was analyzed and the most suitable design of bank was determined.

(1) Conditions of Analysis

Based on the geological profile along the diversion channel (Supporting Report Part B), cross section for the bank stability analysis was assumed as shown in Figure-E12.4.

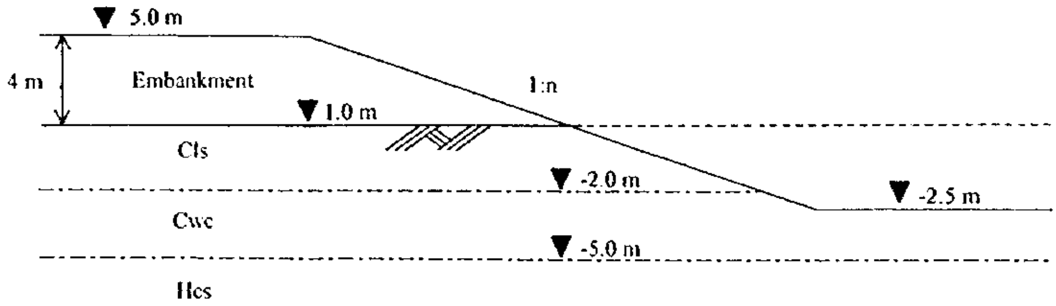


Figure-E12.4 Cross Section for Bank Stability Analysis

Soil constants were determined based on results of the soil test conducted by the Study Team as a part of the geological survey. The constants are shown in Table-E12.1.

Table-E12.1 Soil Constants for Stability Analysis

Geological Profile	Unit Weight γt (t/m³)	Angle of Internal Friction Ø (°)	Cohesion C (tf/m²)
Embankment	1.8	0	0
Cls (Loose Sand Layer)	1.8	$\phi = 15 + \sqrt{15 \times N}$ $= 15 + \sqrt{15 \times 5}$ $\neq 23$	0
Cwc (Weak Clay Layer)	1.8	0	C = 1/2 × qu = 1/2 × (2.8~5.6) = 1.4~2.8 → 1.5 (tf/m²)
Hcs (Sandy Clay Layer)	1.8	0	C = 1/2 × qu = 1/2 × (11.2~16.3) = 5.6~8.3 → 6.0 (tf/m²)

qu: unconfined compression strength obtainable from soil test
N: N value obtainable from the standard penetration test

(2) Method of Analysis

Circular arc method was employed to analyze the bank stability and its formula is as follows.

$$Fs = \frac{\sum\{c \cdot l + (W - u \cdot b)\cos\alpha \cdot \tan\phi\}}{\sum W \cdot \sin\alpha}$$

where,

Fs	:	Safety Factor ≥ 1.2
C	:	Cohesion (tf/m^2)
l	:	Arc length of divided portion (m)
W	:	Weight of divided portion (tf/m)
u	:	Pore water pressure (tf/m^2)
b	:	Width of divided portion (m)
α	:	Angle formed by a line connecting a center on sliding surface of divided portion and center of sliding arc, and vertical axis (°)
ø	:	Angle of shearing resistance (°)

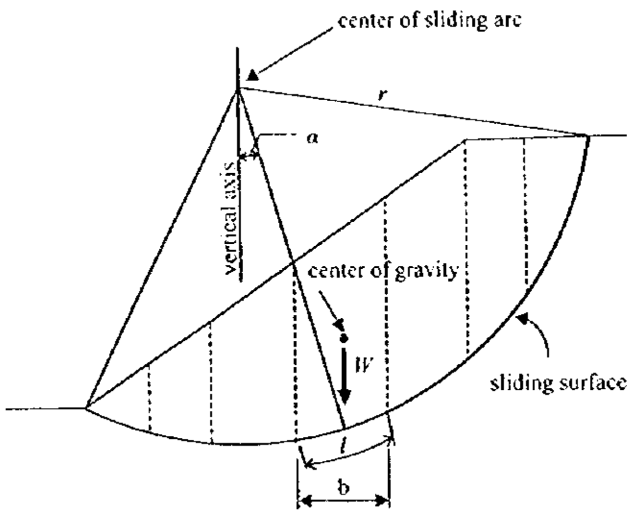


Figure-E12.5 Model of Circular Arc Method

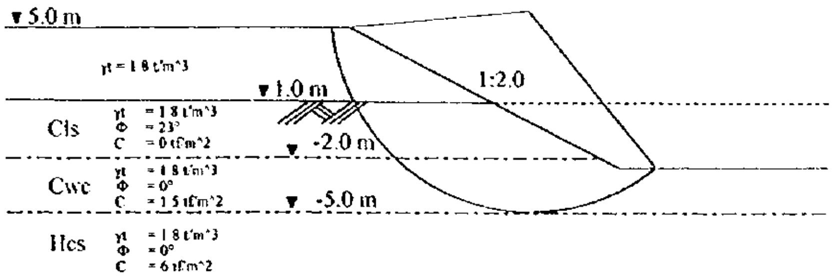
(3) Results

Assuming that height of embankment for the diversion channel is 4 m, the stability analysis of bank by the circular arc method was conducted varying slope gradient of bank, 1:2, 1:3, 1:4 and 1:5. As shown in Figure-E12.6, even 1:5 slope gradient does not satisfy the target safety factor (≥ 1.2) due to too small strength of Cwc layer.

Although the circular arc method was applied varying arc, Figure-E12.6 shows the case of the smallest safety factor calculated of each slope gradient as a critical case.

Case-1

Fs = 0.691



Case-2

Fs = 0.833

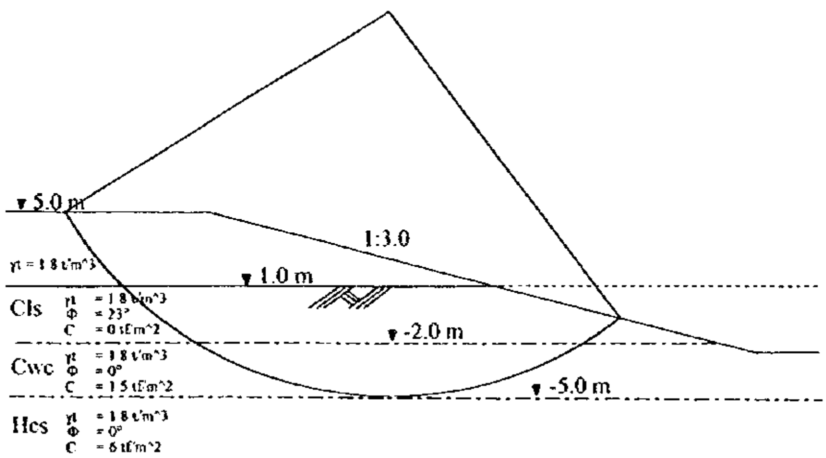
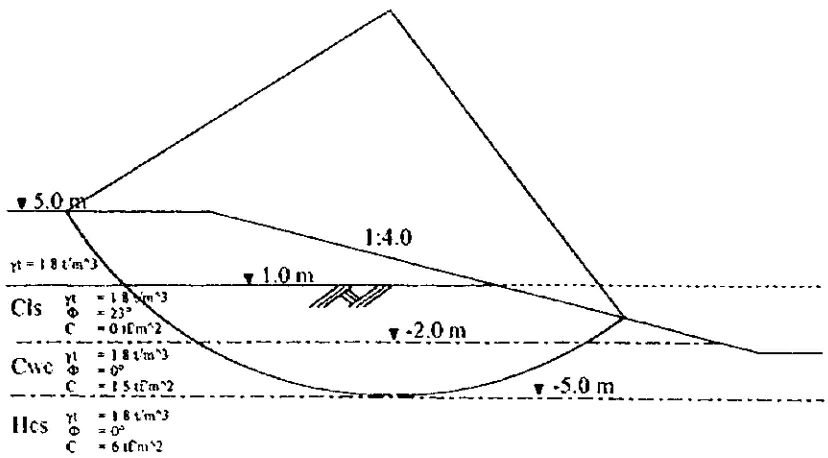


Figure-E12.6 (1/2) Bank Stability Analysis

Case-3

Fs = 0.987



Case-4

Fs = 1.128

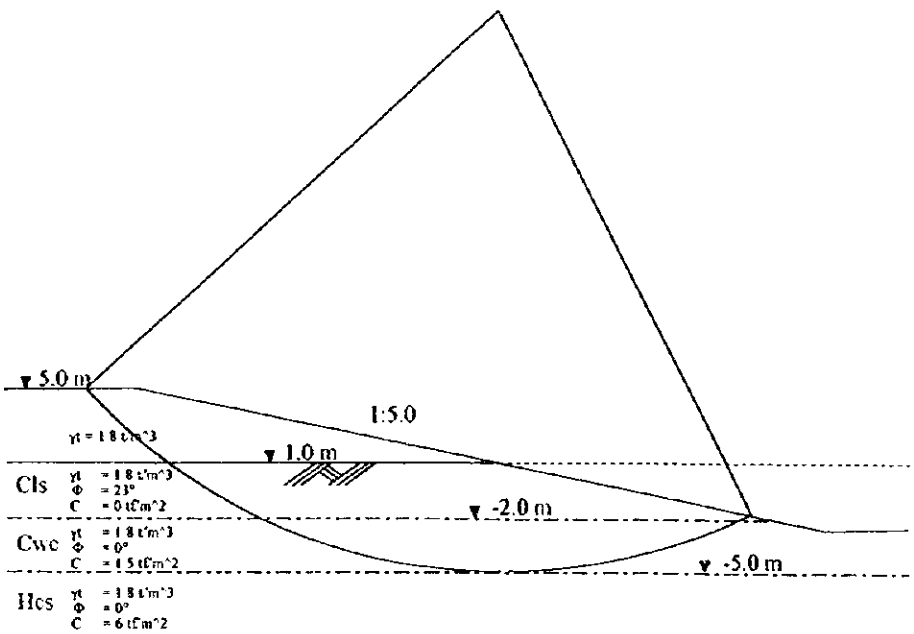


Figure-E12.6 (2/2) Bank Stability Analysis

(4) Countermeasures for Loose Layers

As a result of the bank stability analysis, countermeasures to increase the strength of loose layers are necessary to stabilize the bank. Considering the followings, pre-loading method was adopted to improve the loose layers. The pre-loading method is to make embankment on the present land surface before actual construction starts, to accelerate consolidation in loose layers by load of the embankment. After the strength of loose layers is improved by consolidation, cutting and actual embankment for the diversion channel is conducted.

- Critical layer of bank stability is Cwc, which is the weak clay layer and its depth in the site is not thick, approximately 3 m at maximum.
- Since Cls (loose sand layer) overlays on Cwc, drainage distance by consolidation is short, approximately 3 m at maximum. Therefore, the strength of Cwc is expected to increase by consolidation.
- Cost of pre-loading is relatively cheap compared to other measures and it does not require any special construction machinery or plant.

Considering an advantage of gentle slope in bank stability, slope gradient was determined as 1:3. Since to locate a bank away from top of cutting slope reduces load on arc resulting in increase of stability, embankment was designed 3 m away from top of cutting slope as shown in Figure-E12.7.

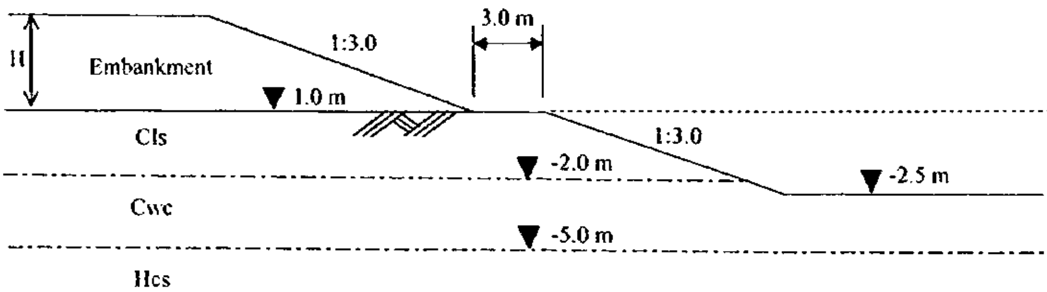


Figure-E12.7 Cross Section for Bank Stability Analysis with Countermeasures

Applying the cross section above (Figure-E12.7), stability analysis by the circular arc method was conducted varying height of embankment and strength of loose layer and the results are shown in Table-E12.2 and Figure-E12.8.

Table-E12.2 Results of Bank Stability Analysis with Countermeasures

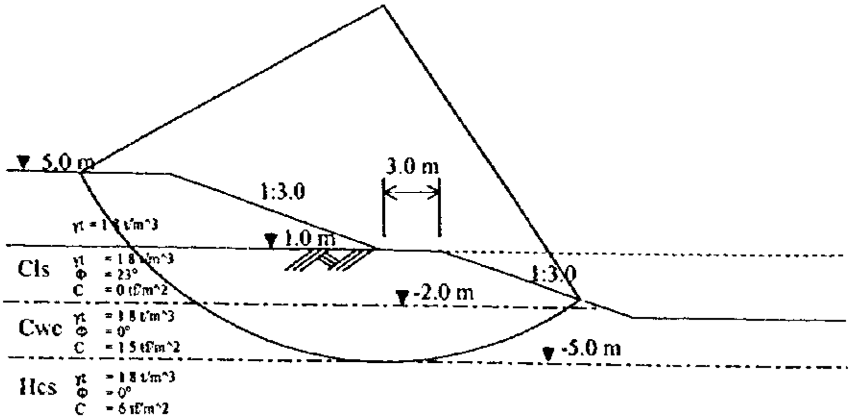
Case No.	Slope Gradient	Width of Berm (m)	Strength of Loose Layer C (tf/m²)	Height of Embankment (m)	Safety Factor	Distance between Bank Crest and Soil Disposal Site (m)
1	1 : 3.0	3.0	1.5 (present)	4.0	0.907	
2	1 : 3.0	3.0	2.0	4.0	1.129	
3	1 : 3.0	3.0	2.5	4.0	1.348	
4	1 : 3.0	3.0	3.0	4.0	1.563	
5	1 : 3.0	3.0	2.5	5.0	1.199	
6	1 : 3.0	3.0	3.0	5.0	1.387	
7	1 : 3.0	3.0	2.5	6.0	1.078	
8	1 : 3.0	3.0	3.0	6.0	1.242	
9	1 : 3.0	3.0	2.5	6.0	1.177	5.0
10	1 : 3.0	3.0	2.5	6.0	1.295	10.0

As a result of the bank stability analysis, necessary height of embankment for the diversion channel, 4 m, is possible to be implemented if the strength of loose layer is improved from 1.5 tf/m^2 to 2.5 tf/m^2 by pre-loading.

Left bank side in the lower reach of the channel is designed for soil disposal area. To minimize the area of the disposal site, embankment of surplus soil higher than bank of the diversion channel is preferable. As shown in Figure-E12.8 (Case 10), stability of bank can be maintained even if embankment of surplus soil is 2 m higher than bank crest of the diversion channel; however, the soil disposal area has to be 10 m away from top of slope of the diversion channel.

Case-1

Fs = 0.907



Case-2

Fs = 1.129

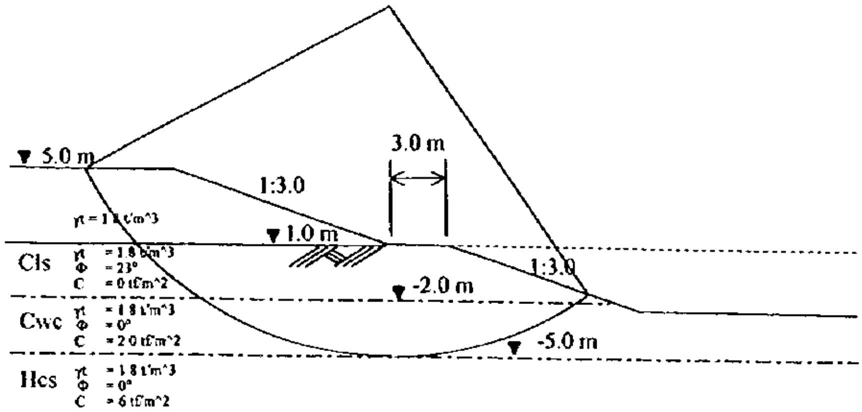
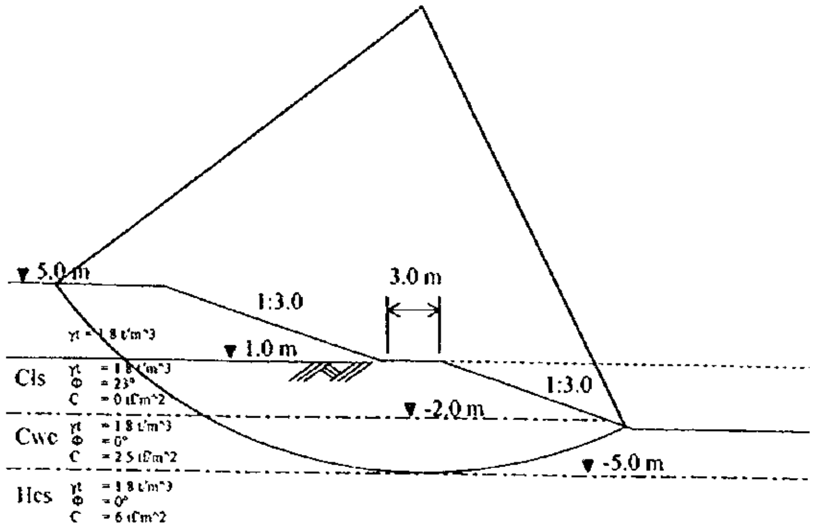


Figure-E12.8 (1/5) Bank Stability Analysis with Countermeasures

Case-3

Fs = 1.348



Case-4

Fs = 1.563

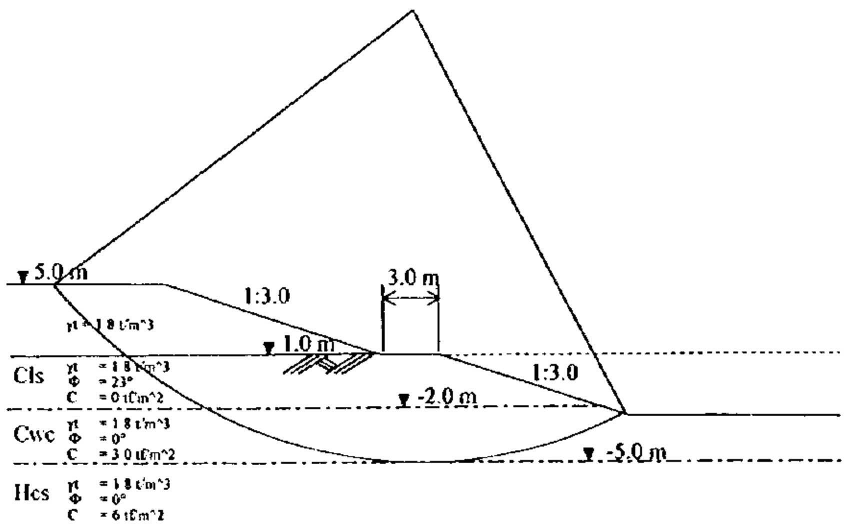
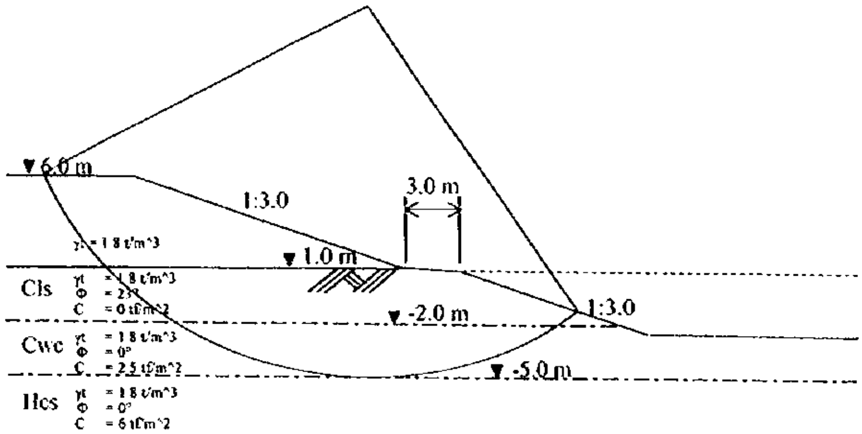


Figure-E12.8 (2/5) Bank Stability Analysis with Countermeasures

Case-5

Fs = 1.199



Case-6

Fs = 1.387

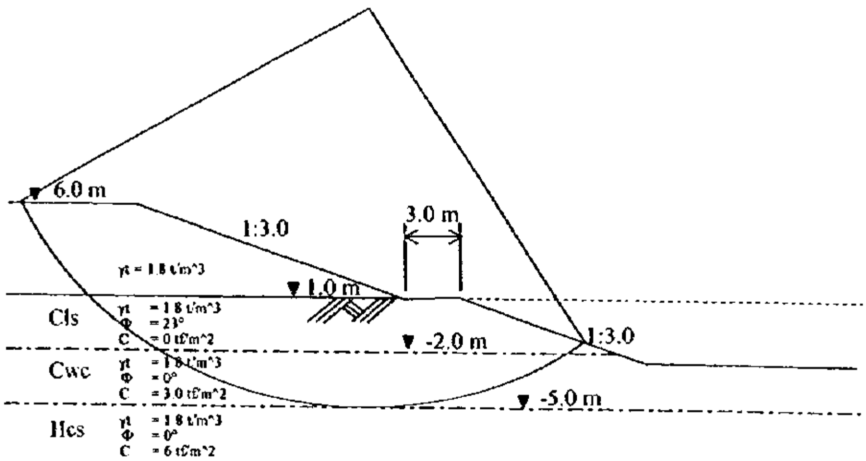
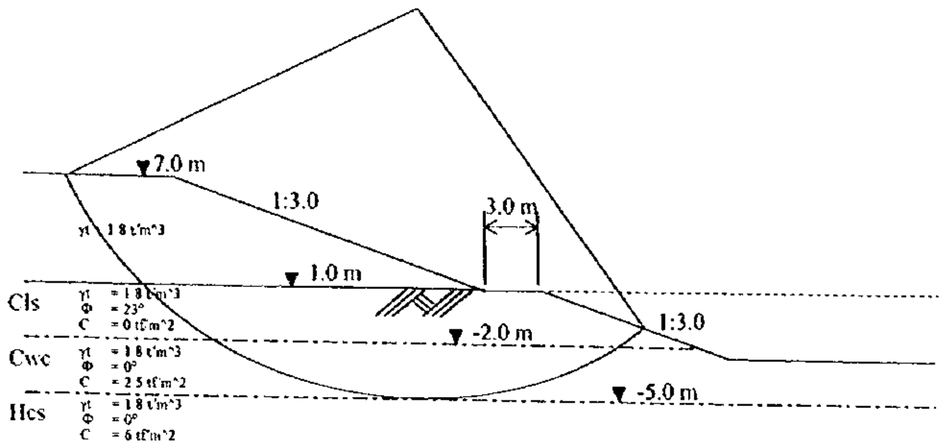


Figure-E12.8 (3/5) Bank Stability Analysis with Countermeasures

Case-7

Fs = 1.078



Case-8

Fs = 1.242

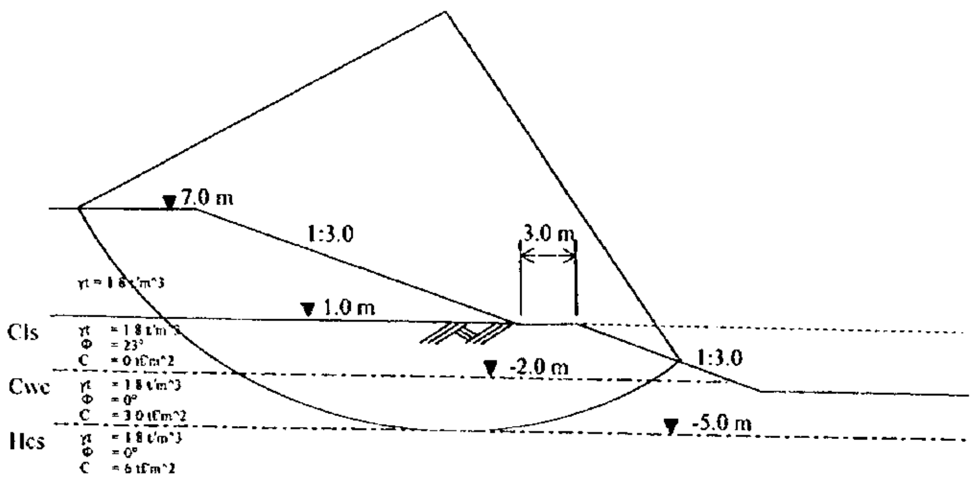
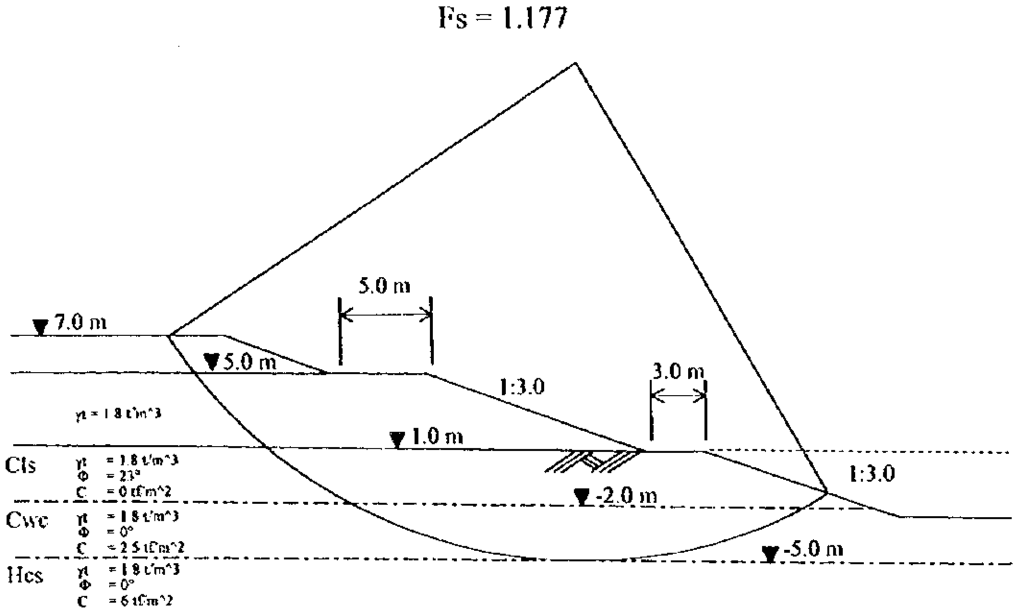


Figure-E12.8 (4/5) Bank Stability Analysis with Countermeasures

Case-9



Case-10

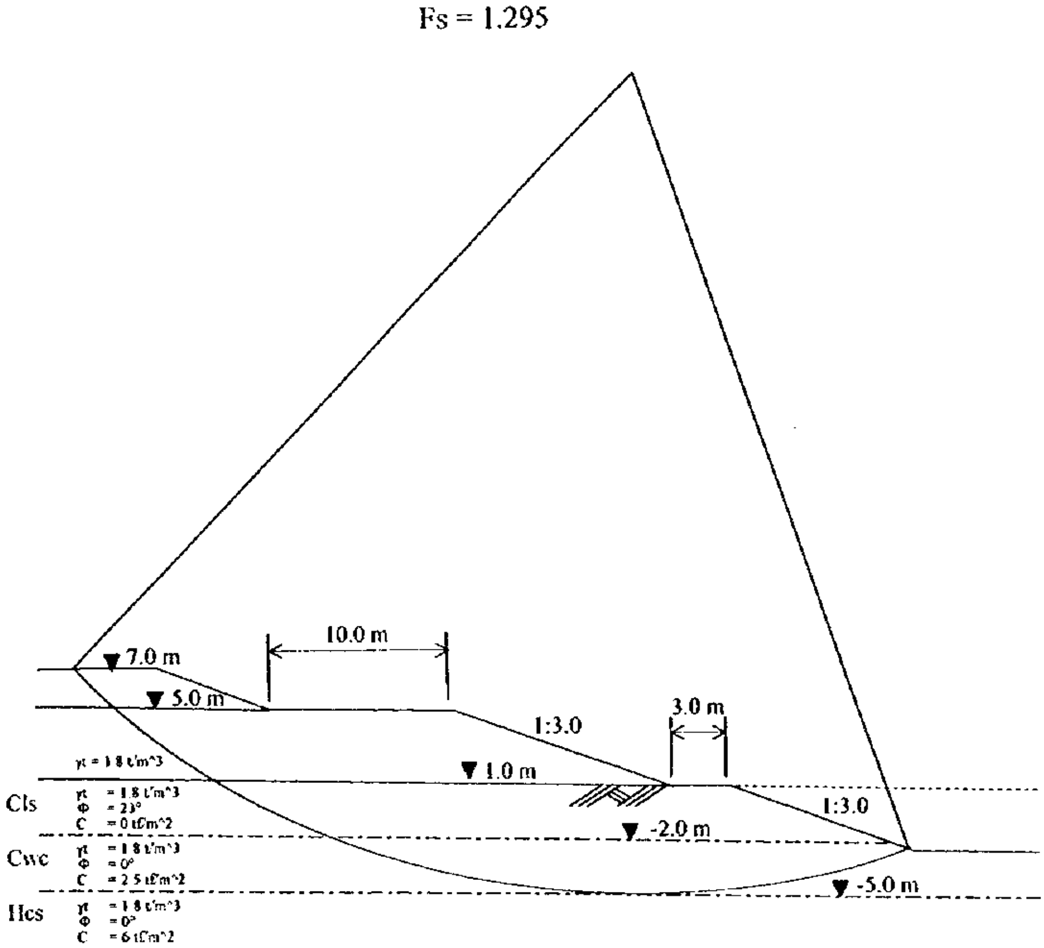


Figure-E12.8 (5/5) Bank Stability Analysis with Countermeasures

(5) Bank Height for Pre-loading

Necessary bank height of pre-loading was determined with the following conditions.

- Target is to increase the strength of Cwc layer from 1.5 tf/m^2 to 2.5 tf/m^2.
- Period required for consolidation is assumed to be within 3 months.
- Coefficient of consolidation is 38 m^2/year assuming that bank height is 2.5 m (Table-12.3).

Table-E12.3 Coefficient of Consolidation based on Consolidation Test

Bank Heights	Coefficient of Consolidation (m^2/year)
0 ~ 1.4 m	15 ~ 103 Average 64
1.4 ~ 2.8 m	22 ~ 64 Average 38
2.8 ~ 5.7 m	14 ~ 35 Average 22
5.7 ~ 11.3 m	4 ~ 15 Average 9

Coefficient of consolidation was obtained from the consolidation test conducted by the Study Team.

Formula to determine period required for consolidation is as follows.

Time coefficient in the formula is read from Figure-E12.9, assuming that degree of consolidation is 90 %.

$$t = \frac{D^2}{Cv} \cdot Tv \cdot 12\,\text{months}$$

where,

t : Period required for consolidation

Cv : Coefficient of consolidation = 38 (see Table-E12.3)

D : Drainage distance = 3 m

Tv : Time coefficient determined by degree of consolidation (U) with Figure-E12.9

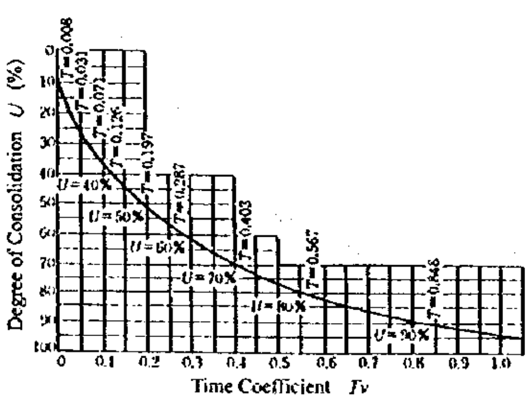


Figure-E12.9 Relation between U and Tv

When bank height is 2.5 m and degree of consolidation is 90 %, period required for consolidation is;

$t = 3^2/38 \times 0.848 \times 12 = 2.4$ months < 3 months

Since degree of consolidation is expected to be 90 % for the case that bank is left for 2.4 months, 3 months was adopted as period for consolidation so that degree of consolidation will be more than 90 %.

Improvement of the strength of Cwc layer was examined by the following formula.

$$Cu = Cu_0 + m\Delta pU$$

where,

- Cu : cohesion after pre-loading (tf/m^2)
- Cu_0 : cohesion of present soil before pre-loading = 1.5 tf/m^2
- m : rate to increase strength = 0.3 (empirical figure)
- Δp : increase stress by bank loading (tf/m^2) = unit weight × bank height
- U : degree of consolidation = 0.9

As mentioned before, bank height is assumed to be 2.5 m. Therefore, cohesion after pre-loading for 3 months is;

$$Cu = 1.5 + 0.3 \times (1.8 \times 2.5) \times 0.9 = 2.72 \text{ tf/m}^2 > 2.5 \text{ tf/m}^2$$

Therefore, the strength of Cwc layer can be improved to the necessary strength, 2.5 tf/m^2, by pre-loading of 2.5 m bank. Total volume of soil required for pre-loading is approximately 260,000 m^3. As shown in Figure-E12.10, the bank for pre-loading consists of two parts. One is to be used as a bank of the diversion channel and another is to be removed after pre-loading. Since works of the former is included in embankment works of the diversion channel, only the latter is considered as works for pre-loading. Therefore, actual volume of soil required for pre-loading itself is 120,000 m^3.

Excavated soil in the cutting section is used for the pre-loading. Since the total volume of excavation in the cutting section is approximately 1,590,000 m^3, volume of soil is sufficient for the pre-loading.

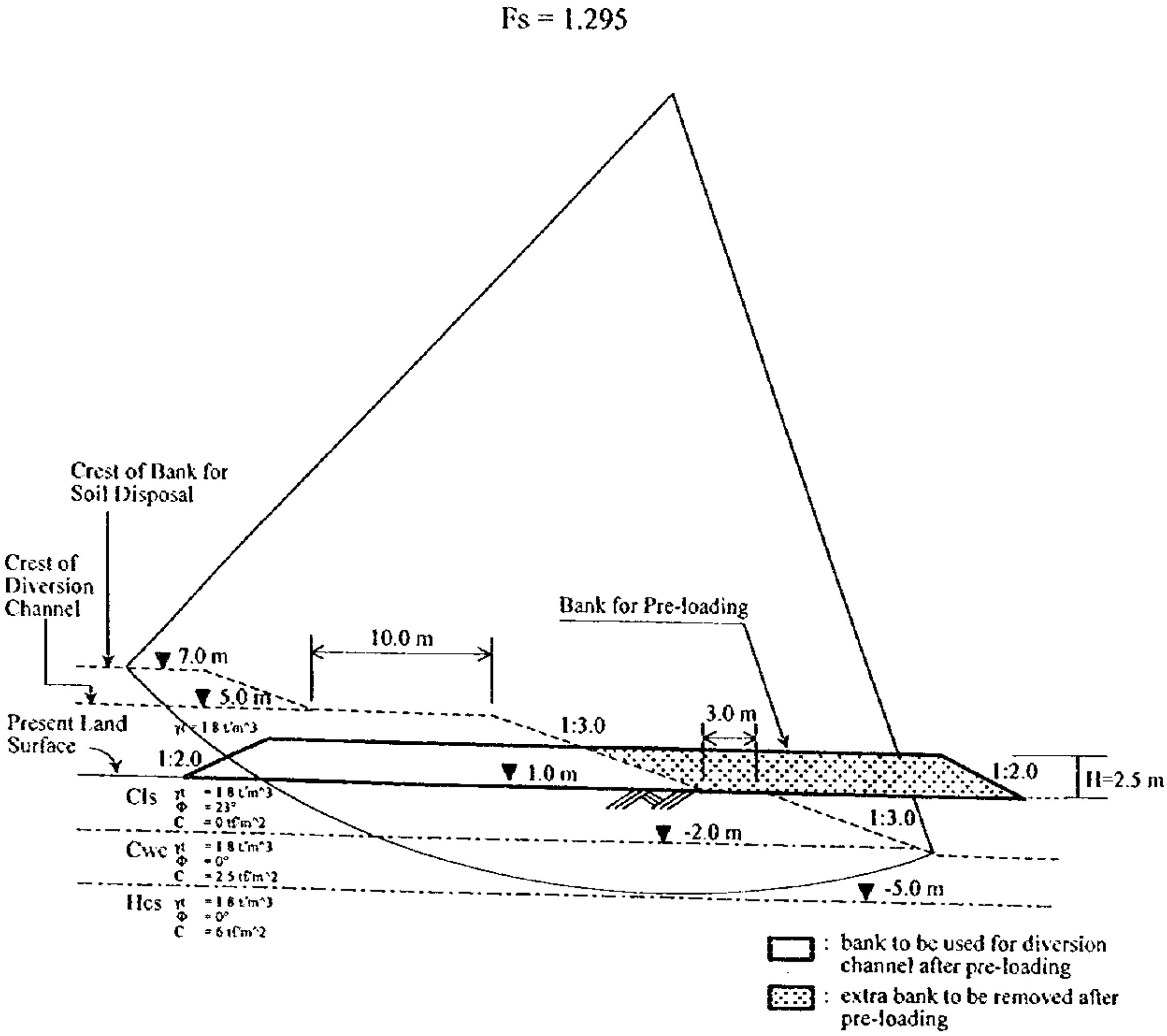


Figure-E12.10 Cross Section of Pre-loading

12.3.5 Disposal Site of Surplus Soil

Some of surplus soil (excavated soils) is used for embankment of the diversion channel, while the rest of soil is dumped in the disposal area located on the left bank side in the lower reach of the channel. The maximum height of the disposal area is 6 m based on the bank stability analysis, and the disposal area is 10 m away from top of slope of the diversion channel (Figure-E12.8, Case-10). Necessary area of the disposal site is 49 ha.

12.3.6 Material for Embankment

Material for embankment is necessary to satisfy the following conditions.

- Fine particles (less than 0.075 mm) are contained more than 15 % in soils whose particle sizes are less than 75 mm to have impermeable property.
- The maximum particle size is less than 10 ~ 15 cm to enable compaction effectively.

- Soil material has enough strength for trafficability of construction machinery and its moisture content is not too high.

According to the soil test conducted by the Study Team as a part of the geological survey, most of soils to be excavated satisfy the above conditions, except Rgs (gravelly sand layer), Cws (weak silt layer) and Cwc (weak clay layer). Rgs, Cws and Cwc are distributed partially in the geological profit along the diversion channel. Therefore, surplus soils (excavated soils) can be used for embankment of the diversion channel in terms of quality and quantity.

12.3.7 Structures of Diverting Point

According to the hydraulic design, 20 year return period flood is drained through the diversion channel with discharge of 1,500 m^3/sec and Nadi river with discharge of 300 m^3/sec. Diverting point is 14.6 km point of Nadi river from river mouth.

The following structures are required for the diverting point and their design is discussed below.

- separation structure
- bank and bed protection
- dike on the left bank of Nadi river in the upstream from diverting point

(1) Separation Structure

Separation structure was designed considering the following items and the results are shown in Figure-E12.11 and Figure-E12.12.

1) Bed widths of Nadi river and the diversion channel are 10 m and 60 m, respectively, based on the hydraulic design.
2) Bed elevations of Nadi river and the diversion channel at inlet are EL. -1.0 m and EL. 0.0 m respectively so that drainage through the channel starts when discharge of Nadi river is 15 m^3/sec.
3) Cross section at diverting point needs to be fixed to allocate discharge to Nadi river and the diversion channel in accordance with the hydraulic design. Therefore, bank and bed protection works at diverting point are required for prevention of erosion and stability of bank. The section between 50 m upstream and downstream from diverting point was designed to apply bank and bed protection works.
4) Partition wall between Nadi river and the diversion channel is required. Partition wall whose length is 90 m was designed by cast-in-place concrete.
5) The diversion channel is close to Nadi river in the downstream from diverting point, which is the left bank of the channel between 2,900 m and 3,100 m from outlet. This section requires bank protection work.

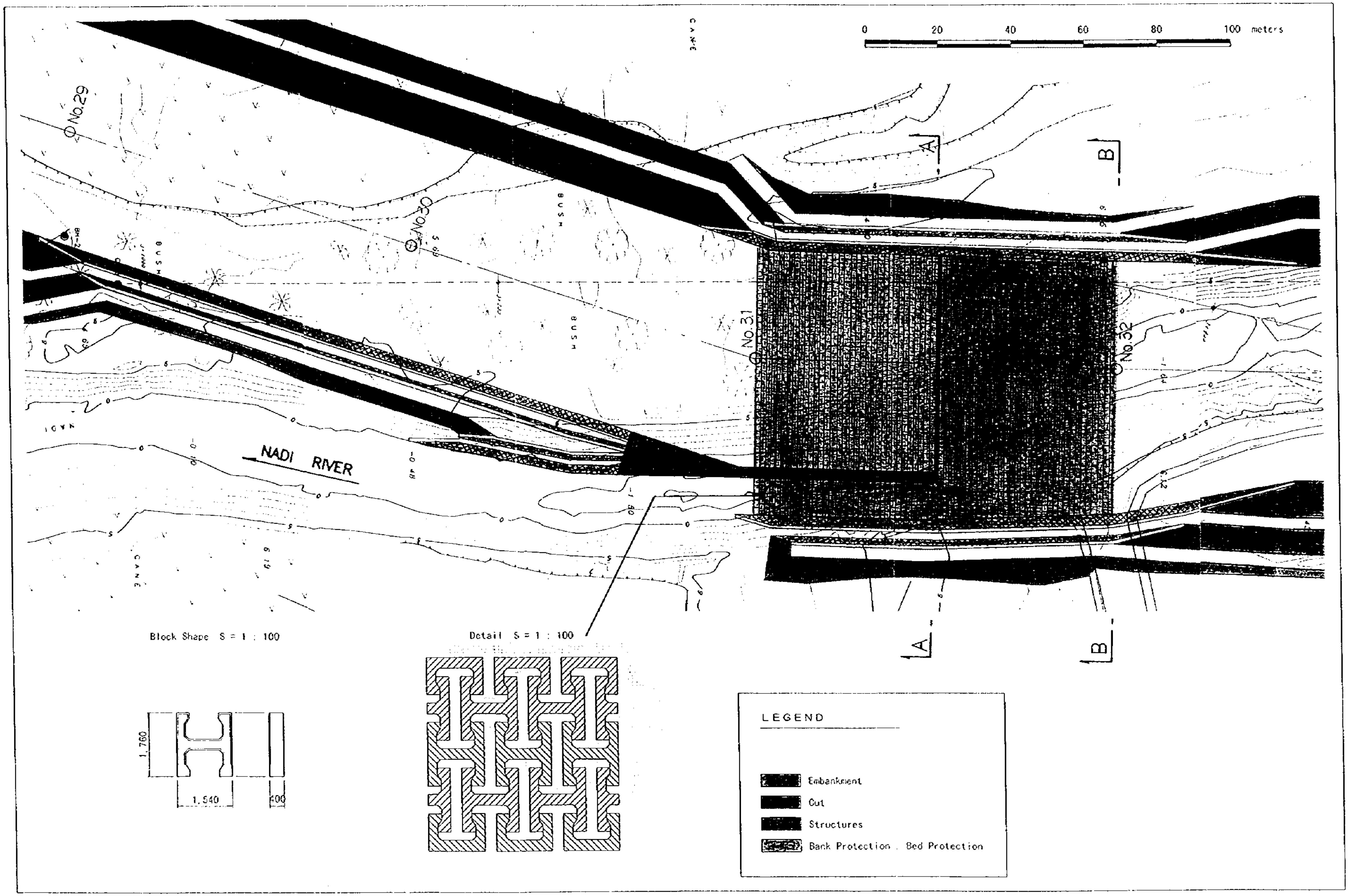
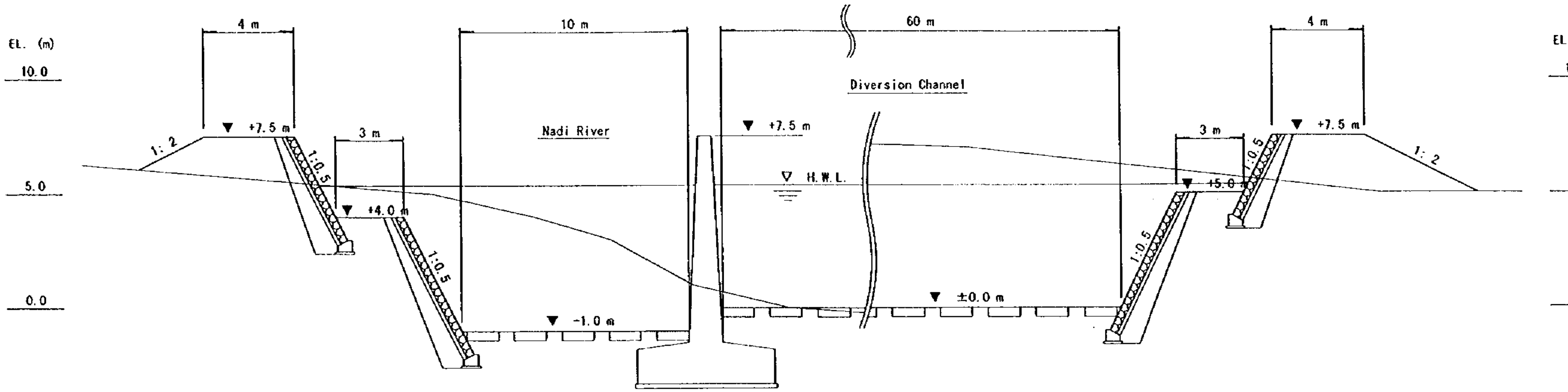
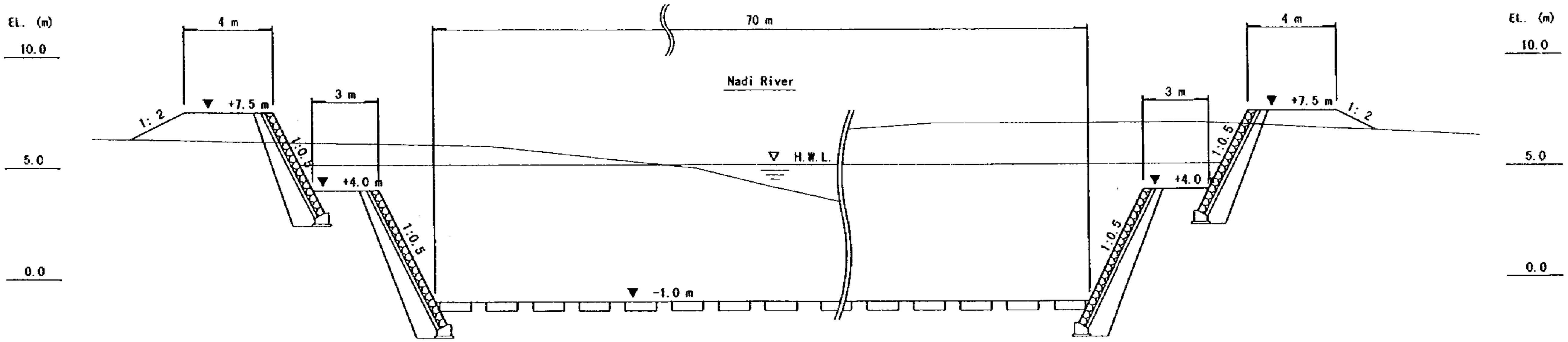


Figure-E12.11 Plan of Diverting Point (20 Year Return Period Flood)



A - A (No. 31+50)



B - B (No. 32)

Figure-E12.12 Cross Section of Diverting Point (20 Year Return Period Flood)

(2) Bank and Bed Protection Works

Block masonry with concrete secondary products are applied to the bank protection work, while blocks (concrete secondary products) with 1 ton/block weight are laid on bed for bed protection work. Dimension and arrangement of those blocks are shown in Fgure-E12.11 and Figure-E12.12.

(3) Dike

After construction of the diversion channel, the design flood (20 year return period flood) is drained through the channel and Nadi river without inundation in the downstream from diverting point; however, flow capacity of Nadi river is not sufficient for the design flood in the upstream from diverting point. Therefore, dike on the left bank of Nadi river in the upstream from diverting point is proposed to prevent overflow on the left bank side of Nadi river from flowing into the river in the downstream.

Alignment of dike starts near the survey point No. 35 and runs perpendicularly to Nadi river until Nadi backroad as shown in Figure-E12.1 (3/3). The dike also connects the banks at diverting point and near No. 35 (starting point) along Nadi river. Elevation of bank crest is EL. 9.0 m and bank height is 3 m in average. Since the crest is used as unpaved road, crest width is 4 m.

12.4 Design of Bridge

(1) Objectives

The following three bridges are planned to provide the access crossing the diversion channel.

1) Queens Road Bridge

A bridge whose scale is same as Sigatoka and Ba bridges constructed recently was planned at the crossing of Queens road and the diversion channel. Roadway consists of 2 lanes and foot way is located at both sides.

2) Sugarcane Tramline Bridge

As shown in Figure-E12.11, sugarcane tramlines currently expand east and west direction crossing the proposed site of the diversion channel. Considering the Nadi airport extension plan, a sugarcane tramline bridge was planned to cross the diversion channel at 200 m in the east-south of the current position. The tramline bridge is for the use of sugarcane tram and pedestrians but not for vehicles. In addition, sewage pipe line, electric cable and telephone line are attached to the bridge.

3) Bridge for Pedestrians

Seashore around outlet of the diversion channel is recreation area for the public. Therefore, a pedestrian bridge at the outlet was planned to provide the access along the seashore. The bridge is just for pedestrians.

(2) Design Standards

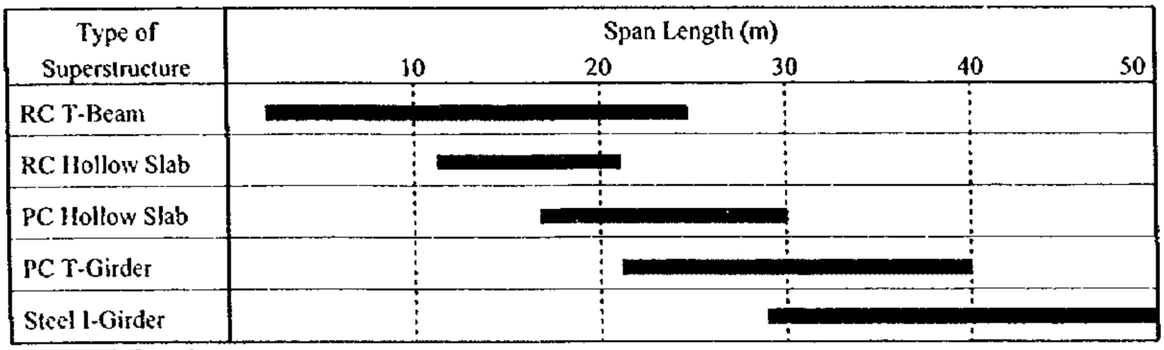
Since there are no design standards in Fiji, bridges in Fiji have been constructed by several countries' standards, such as Australian and New Zealand standards. In this study, Japanese standards (Japanese Specifications of Highway Bridges) was applied.

(3) Structure

In general, superstructure of bridge is classified into reinforced concrete structure, pre-stressed concrete structure and steel structure. Reinforced concrete structure is used for short spans, while pre-stressed concrete and steel structures are used for short, medium and long spans. In Fiji, concrete structures (reinforced and pre-stressed) are common.

In Table-E12.4, type of superstructures is presented according to required span length.

Table-E12.4 Bridge Type and Span Length



RC: reinforced concrete
PC: pre-stressed concrete

(4) Conditions of Foundation

According to the results of geological survey conducted by the Study Team, loose and weak sand and clay layer is distributed at depth from 5 m to 10 m from the ground surface. Hard sand layer underlies the loose and weak sand and clay layer at depth from 8 m to 16 m. Therefore, piles to reach to the hard sand layer are necessary for foundation works.

Pre-stressed concrete pile and deep caisson foundation were adopted for abutments and piers, respectively, considering the popular structures in Fiji and cost.

(5) Bridge Structure

Structures of three bridges were determined as shown in Table-E12.5 considering the above and followings,

- Bridge structures should be economically and structurally sound with an aesthetically pleasing appearance. For economical structures, not only construction cost but also maintenance cost are considered.
- In addition to structural stability of bridge, safety during the construction period should be considered.

Table-E12.5 Selection of Bridge Type

Name of Bridge	Length (m)	Span (m)	Type of Superstructure	Type of Foundation		Grade of Bridge
				Abutment	Pier	
Queens Road	120	3 x 40 m	PC T-Girder	PC Pile	Deep Caisson Foundation	National Road
Sugarcane Tramline	111	3 x 37 m	PC T-Girder	PC Pile	Deep Caisson Foundation	Tram with Footway
Pedestrian	93	3 x 31 m	PC Hollow Slab	PC Pile	Deep Caisson Foundation	Footway

PC: pre-stressed concrete
Length, Span: Figures in the table are for 20 year return period flood.
Type of superstructure and foundation does not vary with scale of target flood.

(6) Bridge Width

Queens road bridge was designed to have same scale as Sigatoka and Ba bridges constructed recently. Therefore, it has roadway of 7.3 m width and foot way of 1.4 m width at both sides. The total width is 10.9 m.

Sugarcane tramline bridge consists of tramline (1.2 m width) and foot way (2.3 m width). The total width is 4.5 m.

The total width of pedestrian bridge is 2.8 m because the bridge is only for pedestrians.

The design of three brides based on the above examination is shown in Figure-E12.13 ~ Figure-E12.15.

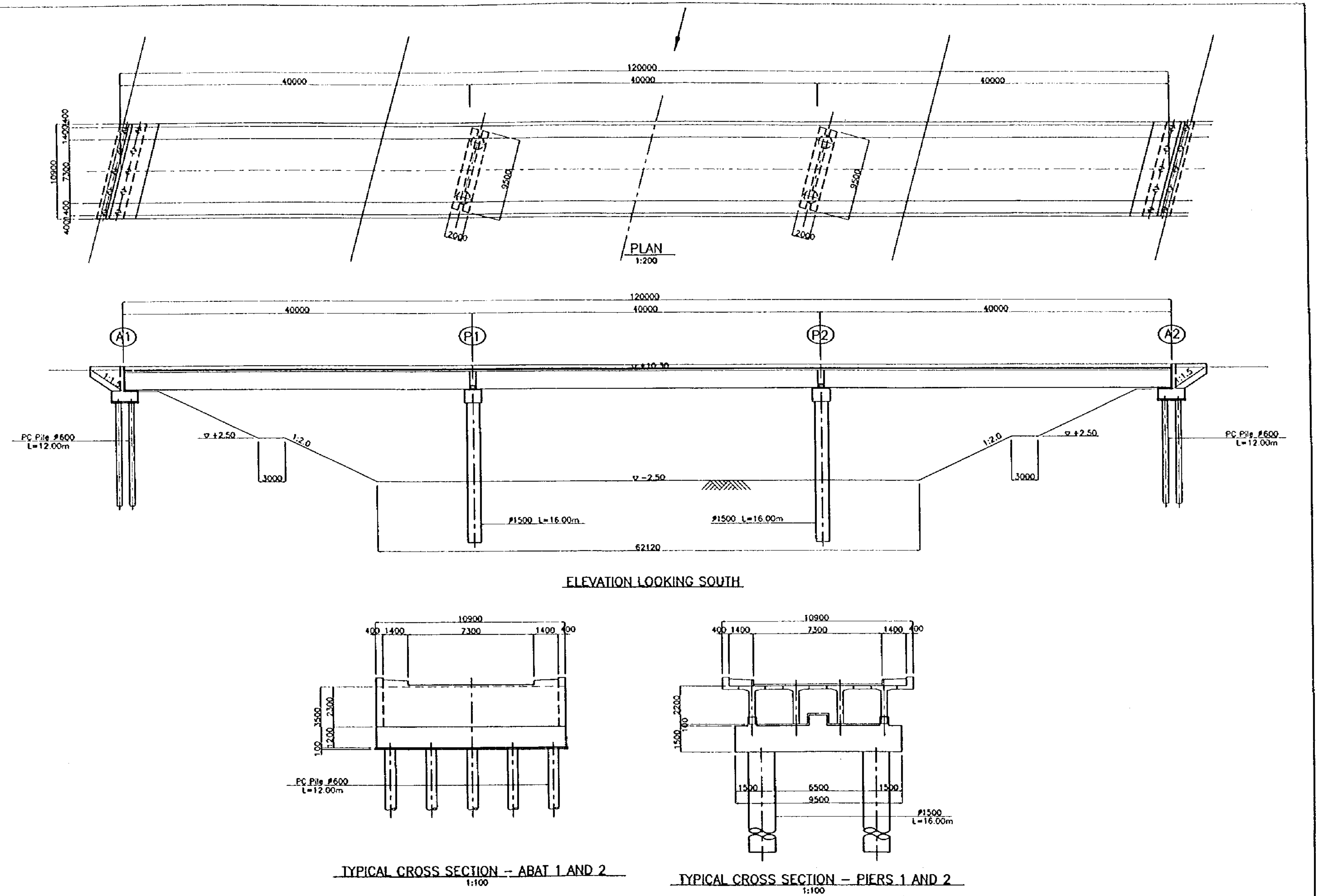


Figure-E12.13 Design of Queens Road Bridge for 20 Year Return Period Flood

JAPAN INTERNATIONAL COOPERATION AGENCY	MINISTRY OF AGRICULTURE, FISHERIES & FORESTS	THE STUDY ON WATERSHED MANAGEMENT AND FLOOD CONTROL FOR THE FOUR MAJOR VITI LEVU RIVERS IN THE REPUBLIC OF FIJI QUEENS ROAD BRIDGE	NADI DIVERSION	YACHIYO ENGINEERING TOKYO	SCALE 1:200 SHEET No 1 OF 3 SHEETS

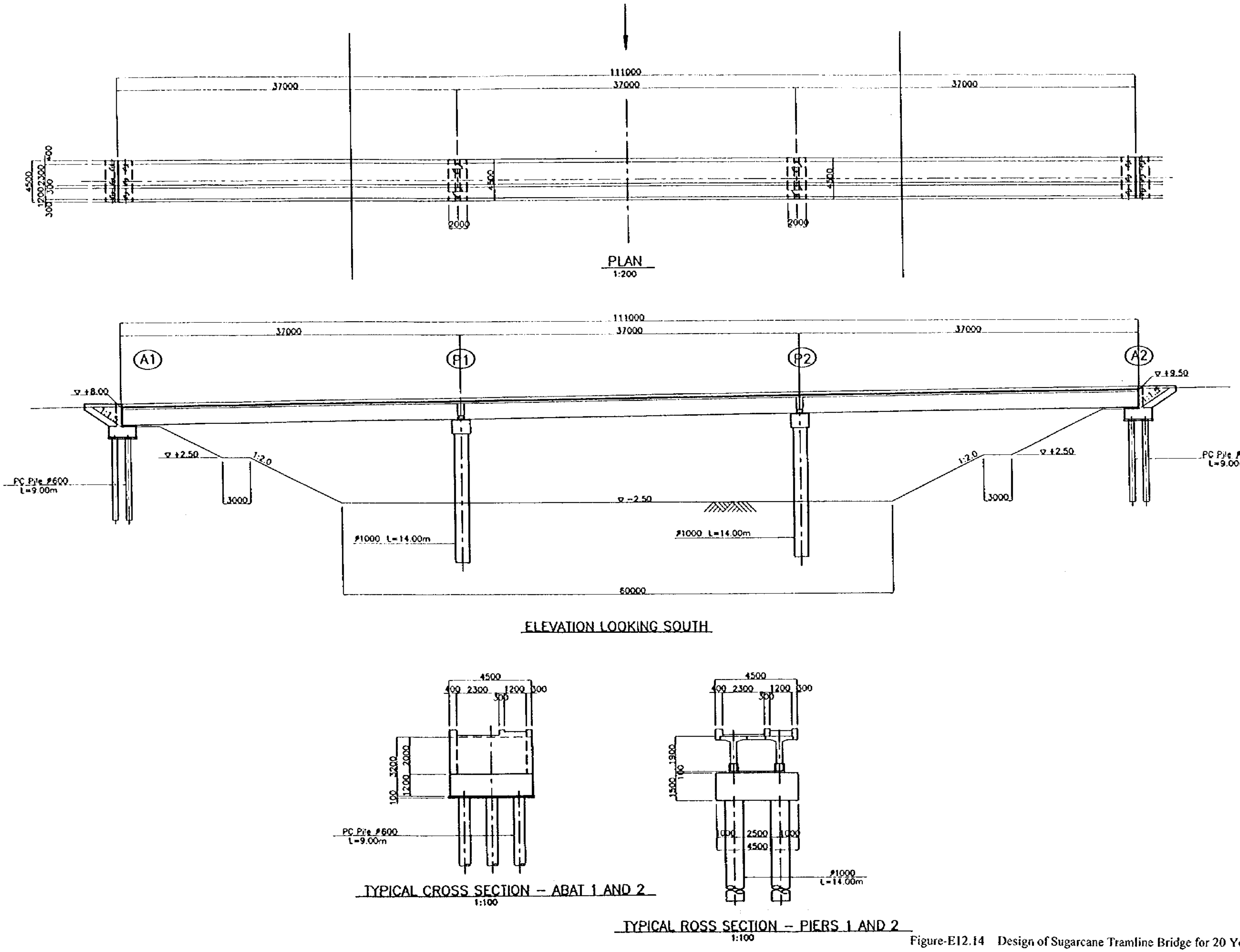


Figure-E12.14 Design of Sugarcane Tramline Bridge for 20 Year Return Period Flood

JAPAN INTERNATIONAL COOPERATION AGENCY	MINISTRY OF AGRICULTURE, FISHERIES & FORESTS	THE STUDY ON WATERSHED MANAGEMENT AND FLOOD CONTROL FOR THE FOUR MAJOR VITI LEVU RIVERS IN THE REPUBLIC OF FIJI SUGARCANE TRAMLINE BRIDGE	NADI DIVERSION	YACHIYO ENGINEERING TOKYO	SCALE 1:200 SHEET No 2 OF 3 SHEETS

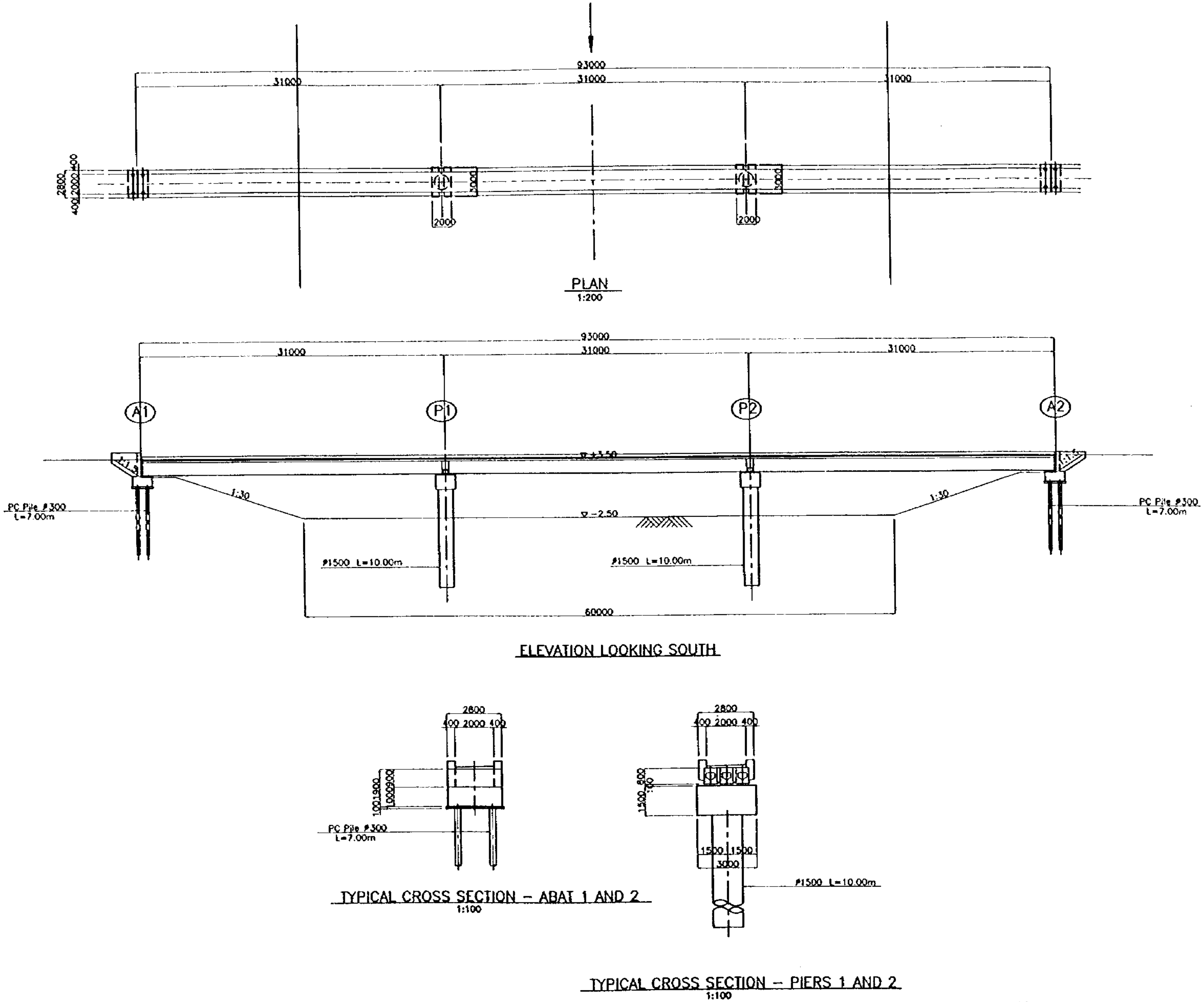


Figure-E12.15 Design of Pedestrian Bridge for 20 Year Return Period Flood

JAPAN INTERNATIONAL COOPERATION AGENCY	MINISTRY OF AGRICULTURE, FISHERIES & FORESTS	THE STUDY ON WATERSHED MANAGEMENT AND FLOOD CONTROL FOR THE FOUR MAJOR VITI LEVU RIVERS IN THE REPUBLIC OF FIJI PEDESTRIAN BRIDGE	NADI DIVERSION	YACHIYO ENGINEERING TOKYO	SCALE 1:200 SHEET No 3 OF 3 SHEETS

12.5 Design of Road

At present, Enamanu road runs along the site of the diversion channel. Therefore, crests of both banks were designed for roads from crossing with Queens Road to outlet. Specifications of roads (paved roads) were determined in accordance with those of Enamanu road upgrading project (Third Road Upgrading Project). Cross section of roads is shown in Figure-E12.16.

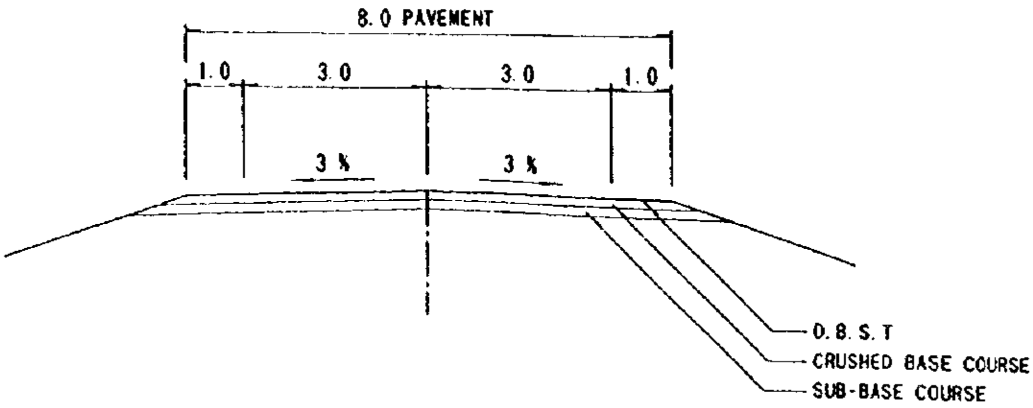


Figure-E12.16 Proposed Cross Section of Road

12.6 Others (Shift Works)

The following works are required as shift works with implementation of the diversion channel. Existing facilities concerned for shift works are shown in Figure-E12.17.

(1) Pipe Lines for Water Supply

There are currently two main pipe lines with diameters of 250 mm and 150 mm along Queens road. In addition, there is a branch line with a diameter of 80 mm along Enamanu road.

Main pipe lines along Queens road were designed to be attached to the proposed Queens road bridge and two branch lines on both banks of the diversion channel were designed to replace the existing branch line.

(2) Sewage Pipe Line

A sewage pipe line with a diameter of 675 mm is located along the sugarcane tramline and the Enamanu pomp station is located in the south-west of the crossing of Enamanu and Tramline roads.

The sewage pipe line was designed to be attached to the sugarcane tramline bridge. Since the present line is under the ground, head of flow may not be sufficient when the pipe line is uplifted to the bridge. In this case, a new pump station is necessary on the right bank of the diversion channel.

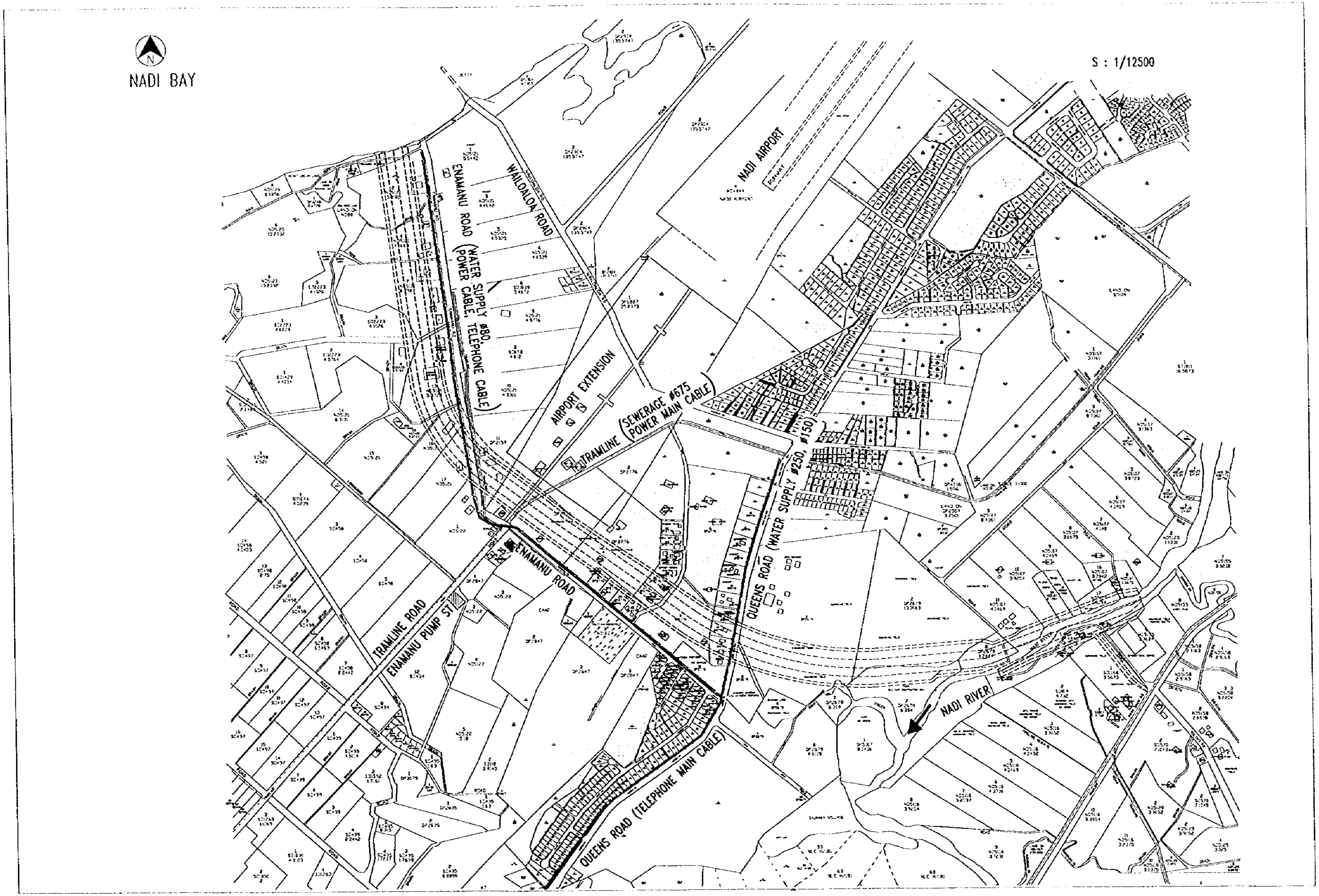


Figure-E12.17 Location of Existing Facilities

(3) Electric Cable

A main electric line (11 kV) runs under the ground along the sugarcane tramline, while a branch line runs above the ground along Enamanu road.

The main electric cable was designed to be attached to the sugarcane tramline bridge and some part of the branch line alignment needs to be changed.

(4) Telephone Line

A main telephone line is located under the ground along Queens road and there is a branch line along Enamanu road.

The main telephone line was designed to be attached to the Queens road bridge and some part of the branch line alignment needs to be changed.

(5) Extension of Nadi Airport

According to Civil Aviation Authority of Fiji (CAAF), the extension of runway is 800 m from the end of the present runway. Guide lights are required at approximately 150 m interval from the end of extended runway and its alignment crosses the diversion channel. Since each location of guide lights can be shifted longitudinally to 6 m ~ 22.5 m depending on position, the diversion channel can be located between two positions of guide lights as shown in Figure-E12.18.

In addition to guide lights, support lights are required at 30 m interval. Necessity of support lights should be discussed with CAAF when the proposed plan (Nadi diversion channel and short cut channel) is realized. If required, 4 piers for support lights are necessary to be located in the cross section of the channel.

There is a cable under the ground along the runway connecting the airport and the transmitter station located in the south of Enamanu road. This cable is designed to be attached to the sugarcane tramline bridge.

(6) Sugarcane Tramline

Alignment of sugarcane tramline has to be changed partially due to the location of the sugarcane tramline bridge. New alignment was determined based on the landuse and design standards of sugarcane tramline, and has been agreed by Fiji Sugar Corporation.

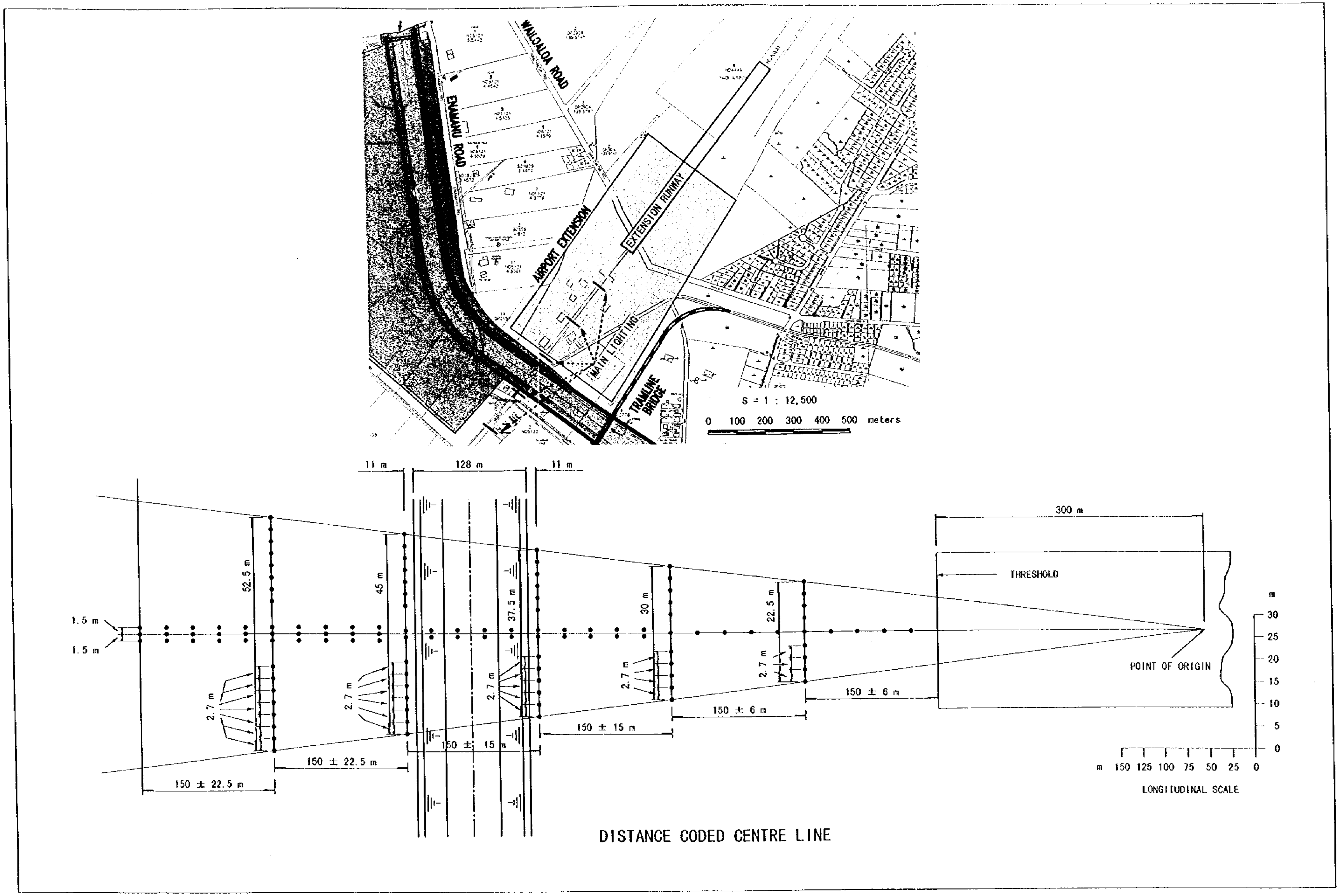


Figure-E12.18 Guide and Support Lights for Nadi Airport Extension