17.4 Selection of Countermeasure for Slope Disaster

17.4.1 Condition of Countermeasure Selection

1) Condition of Falling Stone

Of the 30 disaster prevention spots, 19 spots consist of slopes, of these 19 spots, 14 were sampled for drawing up countermeasures of the falling stones.
These 14 spot are then divided into 9 groups using factor of height, angle, and degree, slope. (See Table 17.3.8, 17.4.1 and Table 17.4.2).
Moreover, stone size is decided by referring the characteristics of slopes (See table 17.3.8).

Table17.4.1 Condition of Fallen Stone

ID No.	Slope Gradient (degree)	Condition of Fallen Rock						
		Slope Height (m)	Slope Gradient (degree)	Size of Rock	Kind of Rock	Density(t/m3)	Conversion to the Volume	
							Density (t/m3)	φ (m)
N001A290	45~52	40	50	1.0m*1.0m*0.8m	Andesite ⅡB	2.5	2.6	1.50
N001A240	45~57	20	50	1.0m*1.0m*0.8m	Andesite ⅡB	2.5	2.6	1.50
N001B230	40~65	30	70	2.0m*1.5m*0.5m	Andesite ⅡB	2.5	2.6	1.50
N001B170	42~70	40	70	2.0m*1.5m*0.5m	Andesite ⅡB	2.5	2.6	1.50
N001B150	50~90	20	70	2.0m*1.5m*0.5m	Andesite ⅡB	2.5	2.6	1.50
N001B120	50~70	50	70	2.0m*1.5m*0.5m	Andesite ⅡB	2.5	2.6	1.50
N003B400	33~90	20	60	2.0m*1.5m*0.5m	Tuff ⅡB	1.7	2.6	1.50
N003B370	45~90	20	60	2.0m*1.5m*0.5m	Tuff ⅡB	1.7	2.6	1.50
N003E170	45~62	20	60	2.0m*1.5m*0.5m	Tuff ⅡB	1.7	2.6	1.50
N005A010	41~48	40	50	2.0m*1.5m*0.5m	Andesite ⅡB	2.5	2.6	1.50
N026A060	53~63	20	70	1.0m*1.0m*0.8m	Tuff ⅡB	1.7	2.6	1.00
N026B140	50~60	40	60	2.0m*1.5m*0.5m	Tuff ⅡB	1.7	2.6	1.50
N026A150	48~70	50	70	2.0m*1.5m*0.5m	Tuff ⅡB	1.7	2.6	1.50
N026B160	53~70	20	70	1.0m*1.0m*0.8m	Tuff ⅡB	1.7	2.6	1.00

2) Calculation of Jumping Height and Rolling Distance

The calculation of jumping height and rolling distance is carried out based on the condition of fallen stone as shown in Table 17.4.1. The purpose of calculating jumping height and rolling distance are as follows:

- Jumping Height: To select appropriate countermeasures for falling stone.
- Rolling Distance: To assess whether or not a change of alignment, or widening of the shoulder is needed countermeasure to prevent falling rock from entering the carriageway.

The results of the above calculations are shown in Table 17.4.2 and Figure 17.4.1. Calculations are based on simulations carried out for each 9 case for a total of ten times. As for the model used for the simulations, it is contained in the design manual.

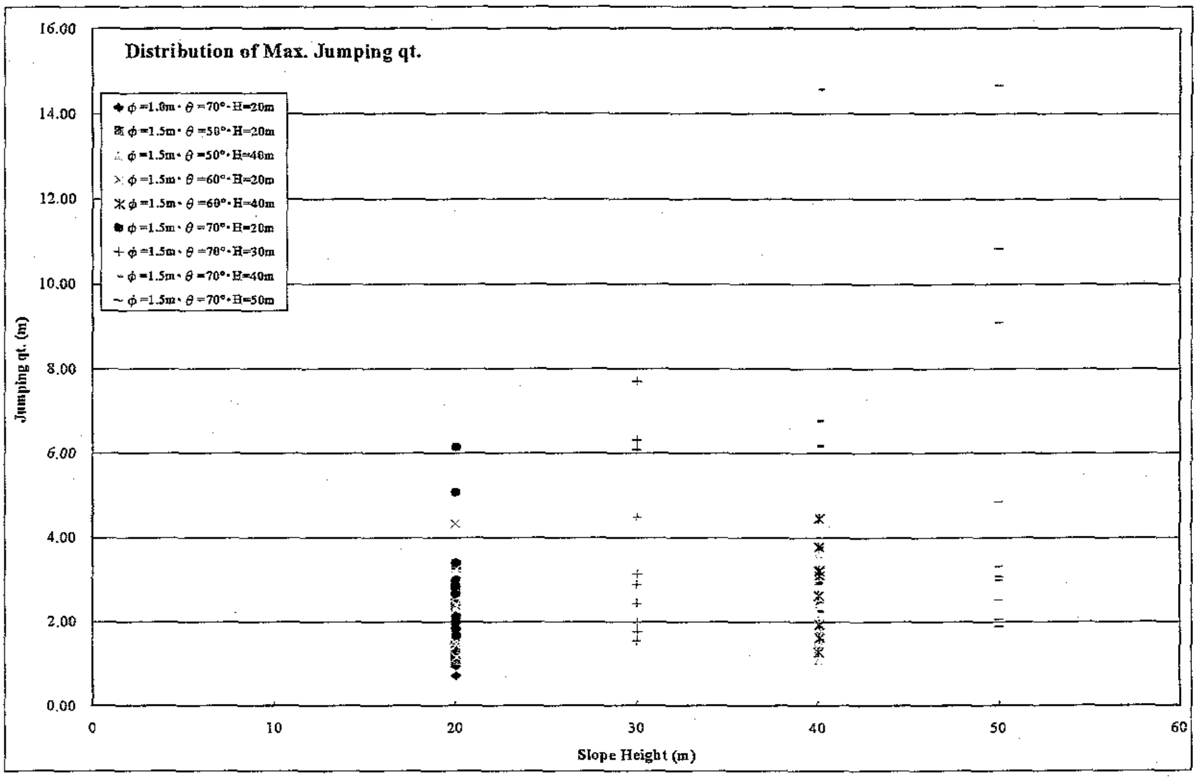
Table 17.4.2 Jumping Height and Rolling Distance Calculations

ID No.	Range of Jumping qt	The ninth value	Range of Rolling qt	The ninth value	f (m)	Slope H (m)	Slope G (deg.)
N026A060 N026A160	0.73 - 2.88m	2.85m	0.40 - 2.68m	2.61m	1.00	20.0	70.0
N001A240	1.05 -3.44m	2.72m	0.38 -3.97m	0.95m	1.50	20.0	50.0
N001A290 N005A010	1.08 -3.62m	2.98m	0.40 - 2.67m	0.97m	1.50	40.0	50.0
N003B400 N003B370 N003E170	1.16 - 4.33m	3.27m	0.39 - 4.50m	3.04m	1.50	20.0	60.0
N026B140	1.28 - 4.45m	3.78m	0.45 - 4.00m	3.20m	1.50	40.0	60.0
N001B150	1.67 - 6.14m	5.08m	0.73 - 5.12m	4.77m	1.50	20.0	70.0
N001B230	1.54 - 7.70m	6.31m	0.52 - 7.80m	6.88m	1.50	30.0	70.0
N001B170	1.57 - 14.56m	6.77m	1.05 - 14.17m	7.43m	1.50	40.0	70.0
N001B120 N026A150	1.89 - 14.65m	10.82m	0.56 - 12.13m	6.97m	1.50	50.0	70.0

As for the values for jumping height and rolling distance, it is derived from many factors, such as the condition of the standing crop, slope structure (unevenness), slope strength (reaction), etc. Therefore, it is a value that is difficult to calculate and fix it as a constant.
Therefore, as a verification method, the second largest value (or 9th value) and the maximum value (or 10th value) for rolling distance and jumping height are compared. If the 10th value is much large than the 9th value, it is considered to be or outlier observations, and disregarded. In that case the 9th value is adopted, while in other case, the 10th value would be adopted.

3) Allowable Range of Countermeasure for Rolling Stones

When a countermeasure is selected, the size of the falling stone that it can cope with and ease of maintenance are important factors to consider. Based on this, the size of protection walls and prevention nets can be decided.



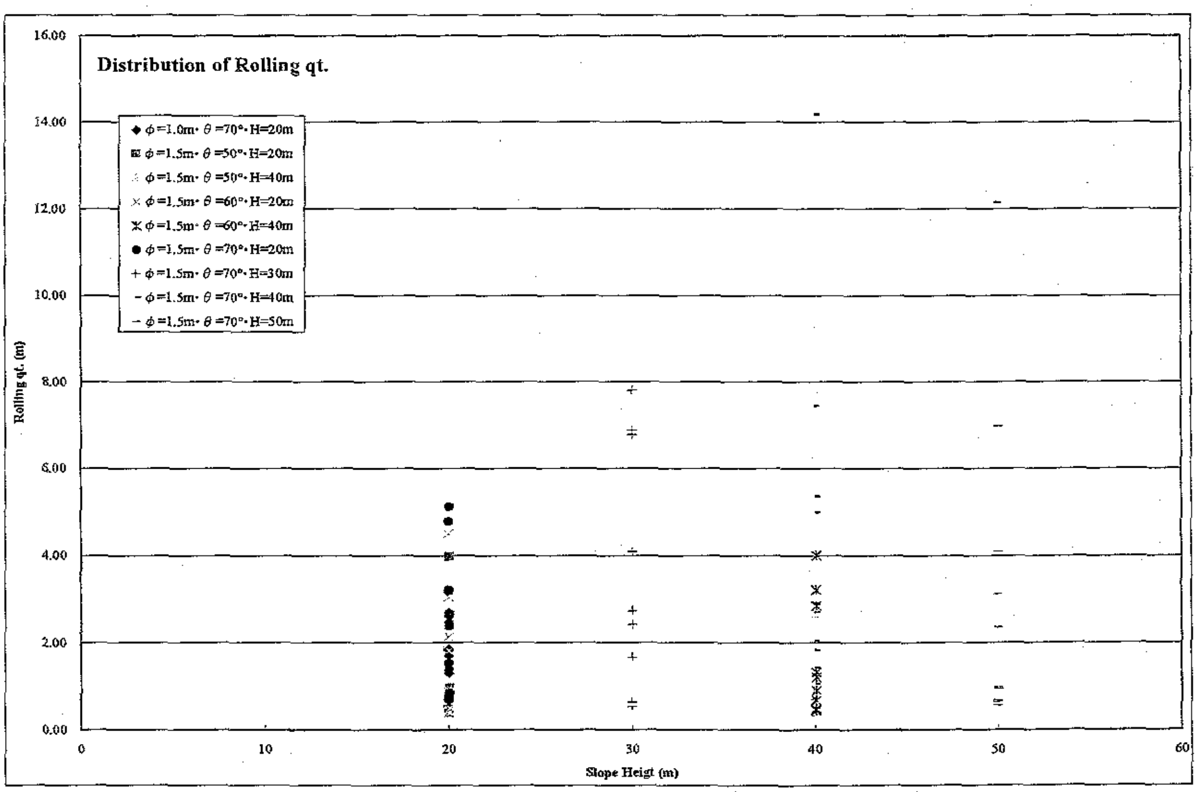
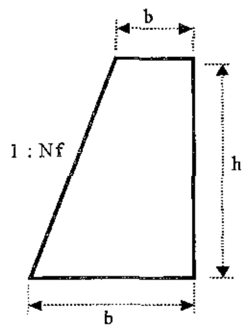


Figure. 17.4.1 Distribution of Jumping Height and Rolling Distance

a) Required Dimensions for Protection Walls

The energy of falling stones was calculated and the necessary structure of protection walls examined for each disaster prevention spot. The results of the examination are shown in Table 17.4.3 and Table 17.4.4.

Table 17.4.3 Structure Required for Protection Wall



Type		Size (m)				
		h	b1	b2	Nf	Em (KJ)
	A	2.00	0.50	1.50	0.50	8.94
	B	2.50	0.75	2.00	0.50	21.01
	C	3.00	1.00	2.50	0.50	40.90
	D	3.50	1.25	3.00	0.50	70.21
	E	4.00	1.50	3.50	0.50	110.41
	F	4.50	1.75	4.00	0.50	163.21
	G	5.00	2.00	4.50	0.50	229.76
	H	5.50	2.25	5.00	0.50	310.77
	I	6.00	2.50	5.50	0.50	406.73
	J	6.50	2.75	6.00	0.50	518.11

Em: Allowable Absorable Energy

Table 17.4.4 Relationship between Type of Protection Wall & Natural Conditions

Boulder Weight	Slope Height	Slope Gradient (degree)					
(kN)	(m)	30	40	50	60	70	80
1.7 (ϕ =0.5m)	10						
	20						
	30						
	40						
	50						
(kN)	(m)	30	40	50	60	70	80
13.6 (ϕ =1.0m)	10						
	20					N026A060 N026B160	
	30						
	40						
	50						
(kN)	(m)	30	40	50	60	70	80
45.9 (ϕ =1.5m)	10						
	20			N001A240	N003B400 N003B370 N003E170	N001B150	
	30					N001B230	
	40			N001A290 N005A010	N026B140	N001B170	
	50					N001B120 N026A150	
(kN)	(m)	30	40	50	60	70	80
108.9 (ϕ =2.0m)	10						
	20						
	30						
	40						
	50						

b) Required Dimensions for Prevention Net

Dimensions for prevention nets, as in the case of protection walls, were examined for each disaster prevention spot. The results of this examination are shown in Table 17.4.5. As for maximum capacity, this is calculated using the formula shown in the design manual.

Table 17.4.5 Required Dimensions for Prevention Nets

ID No.	Rope f 12 Mesh f 2.6							
	Net Data				Rock Data		Slope Data	
	Main Rope	Auxiliary Rope	Wire Mesh	Maximum Capacity	f (m)	W (kN)	Slope H (m)	Slope G (deg.)
N026A060	f 12	f 12	f 2.6	n=1.0	1.00	13.61	20.0	70.0
N026A160								
N001A240	f 12	f 12	f 2.6	NG	1.50	45.92	20.0	50.0
N001A290	f 12	f 12	f 2.6	NG	1.50	45.92	40.0	50.0
N005A010								
N003B400	f 12	f 12	f 2.6	NG	1.50	45.92	20.0	60.0
N003B370								
N003E170								
N026B140	f 12	f 12	f 2.6	NG	1.50	45.92	40.0	60.0
N001B150	f 12	f 12	f 2.6	NG	1.50	45.92	20.0	70.0
N001B230	f 12	f 12	f 2.6	NG	1.50	45.92	30.0	70.0
N001B170	f 12	f 12	f 2.6	NG	1.50	45.92	40.0	70.0
N001B120	f 12	f 12	f 2.6	NG	1.50	45.92	50.0	70.0
N026A150								

ID No.	Rope f 18 Mesh f 4.2							
	Net Data				Rock Data		Slope Data	
	Main Rope	Auxiliary Rope	Wire Mesh	Maximum Capacity	f (m)	W (kN)	Slope H (m)	Slope G (deg.)
N026A060	f 18	f 18	f 4.0	n=6.0	1.00	13.61	20.0	70.0
N026A160								
N001A240	f 18	f 18	f 4.0	n=1.0	1.50	45.92	20.0	50.0
N001A290	f 18	f 18	f 4.0	n=1.0	1.50	45.92	40.0	50.0
N005A010								
N003B400	f 18	f 18	f 4.0	n=1.0	1.50	45.92	20.0	60.0
N003B370								
N003E170								
N026B140	f 18	f 18	f 4.0	n=1.0	1.50	45.92	40.0	60.0
N001B150	f 18	f 18	f 4.0	n=1.0	1.50	45.92	20.0	70.0
N001B230	f 18	f 18	f 4.0	n=1.0	1.50	45.92	30.0	70.0
N001B170	f 18	f 18	f 4.0	n=1.0	1.50	45.92	40.0	70.0
N001B120	f 18	f 18	f 4.0	n=1.0	1.50	45.92	50.0	70.0
N026A150								

4) Calculation of Minimum Required Distance to Roadside Obstacles

As mentioned in Chapter 16, there are a few spots where the sight distance for a road is poor due to such things as an overhanging slope. In such cases, safety can be improved by eliminating the overhang. At spots where sight distance is a problem, such countermeasures may be required to achieve the sight distance needed. Required stopping sight distance is set at 85m based on design speed and the adopted geometric standards. The required minimum distance to roadside obstacles to ensure that stopping sight distance is realized is calculated as shown in the formula below.

Calculation Method of Widening

$E = D^2/8Ra$ — **E**: Required Distance to Nearest Roadside Obstacle from Centerline of Inside Lane of Curve (m), **D**: Sight Distance=85 (m), **Ra**: Radius (m)

Table 17.4.6 Results of Survey on Distance to Roadside Obstacles

ID No.	Radius (m)	Carriageway Width (m)	Existing E (m)	Required Space (m)	Judge
N001A290	1600	7.7	8.49	0.6	OK
N001A280	400	7.5	5.48	2.3	OK
N001A240	250	7.1	4.40	3.6	OK
N001B230	150	7.5	6.29	6.0	OK
N001B170	180	8.7	2.22	5.0	NG
N001B150	290	8.6	4.10	3.1	OK
N001B120	220	8.8	2.22	4.1	NG
N003B400	220	7.3	4.65	4.1	Ok
N003B370	400	6.5	3.69	2.3	OK
N003B320	240	6.8	6.49	3.8	OK
N003B230	140	7.6	3.61	6.5	NG
N005A010	1800	8.1	3.42	0.5	OK
N026A150	150	6.6	5.40	6.0	NG

17.4.2 Countermeasure for Shifting of Road Alignment

One of the countermeasures to avoid the effects of falling stones is to shift the road alignment. The workflow for this countermeasure is as shown in Figure 17.4.2.

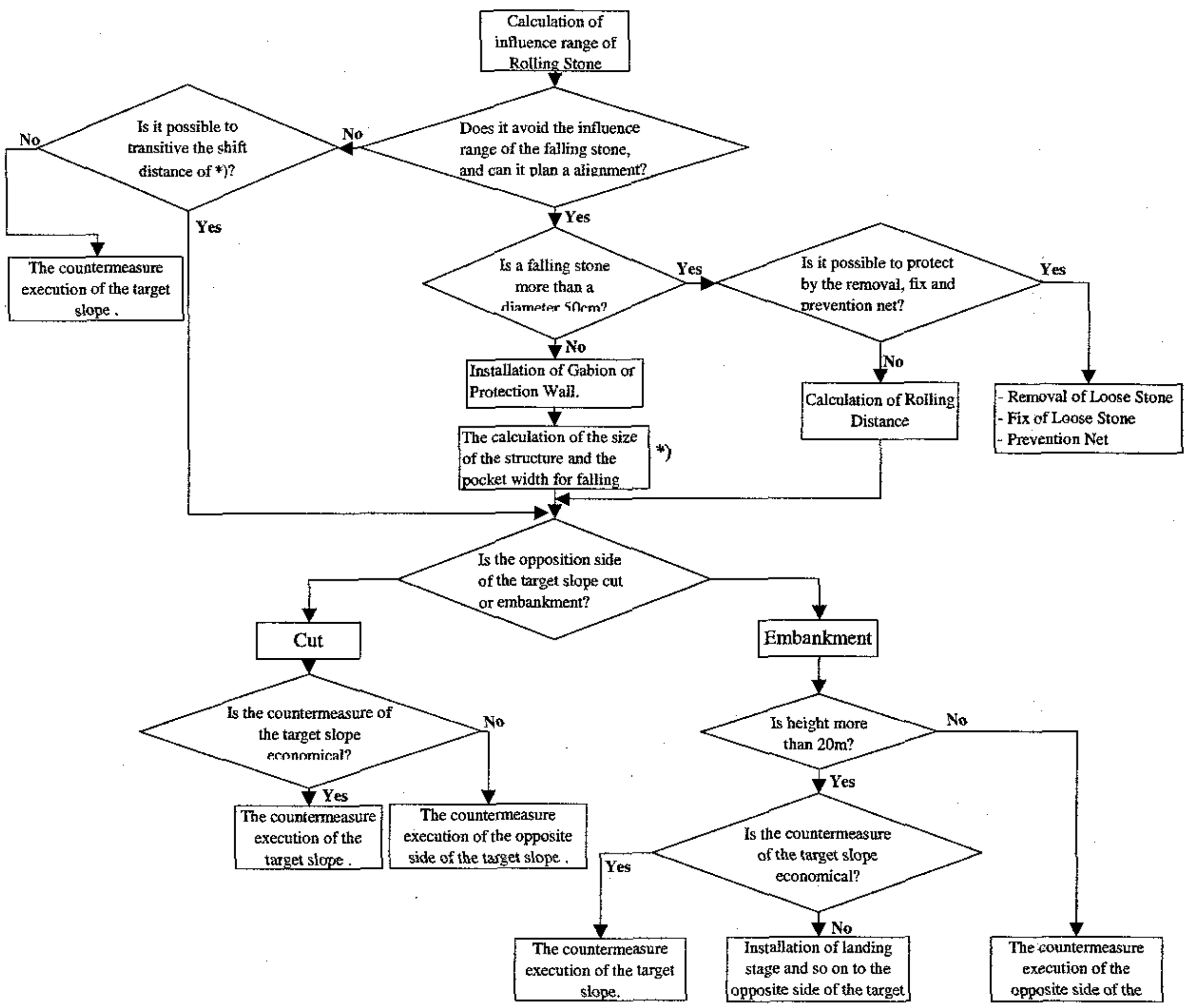


Figure. 17.4.2 Flow of Countermeasure of Road Alignment Shift

Based on the examination of countermeasures in Sub-section 17.4.1 on falling stones, prevention nets should be sufficient to deal with this problem. Therefore, the expensive and time-consuming countermeasure of shifting a road alignment is not carried out. However, the geometric condition of road alignments are examined to see if they satisfy the standard value for minimum curvature. As shown in Table 17.4.7, only N003E170 does not satisfy minimum requirements.

Table 17.4.7 Curvature Radius of Each Spot

ID No.	Standard Min. Radius (m)	Existing Radius (m)	Range of Rolling Qt.
N001A290	135	1600	1.0
N001A240	135	250	1.0
N001B230	135	150	6.9
N001B170	135	180	7.4
N001B150	135	290	5.1
N001B120	135	220	7.0
N003B400	135	200	3.0
N003B370	135	400	3.0
N003B320	135	240	-
N003E170	135	45	3.0
N005A010	135	1800	1.0
N026A060	135	∞	2.7
N026A140	135	250	4.0
N026A150	135	150	7.0
N026A160	135	∞	2.7

The results of the examination of alternative routes for N003E170, in order to avoid the effects of falling rock, are shown in **Figure 17.4.3** and described in **Table 17.4.8.**

Table 17.4.8 Alternative Route Comparison for N003E170

Route	Min. Radius	Vertical Grade	Component of Length	Rough Construction Cost US$1,000	Evaluation
Existing	R=45m	I= 7.9%	—	310	Safety from debris flow and falling stones is secured via curve widening; although, the curve radius does not satisfy geometric design standards. On the other hand, construction cost is the most economical. ○
Route A	R=65m	I=14.3%	**Earth Work: 106m** Embankment ($6{,}500m^3$) **Pavement: $912m^2$** **Br : 97m (805m2)**	1,774	Safety from debris flow and falling stone is secured. However, the curve radius and vertical grade do not satisfy geometric design standards. Also, construction cost is the highest. Because of this, it is inferior to the other alignments. ×
Route B	R=135m	I=14.8%	**Earth Work: 120m** Embankment ($5{,}000m^3$) **Pavement: $1{,}032m^2$** **Br: 93m ($770m^2$)**	1,649	Safety from debris flow and falling stone is secured. However, the vertical grade is larger than the standard value, presenting a problem to the hill climbing ability of large vehicles. Moreover, construction cost is also high. Therefore, this alignment is relatively inferior both in terms of economics and geometric design. △

*) Standard Max. Vertical Grade: 8.0%

17.4.3 Final Selection of Countermeasure

The final countermeasures adopted for each spot are shown in Table 17.4.9.

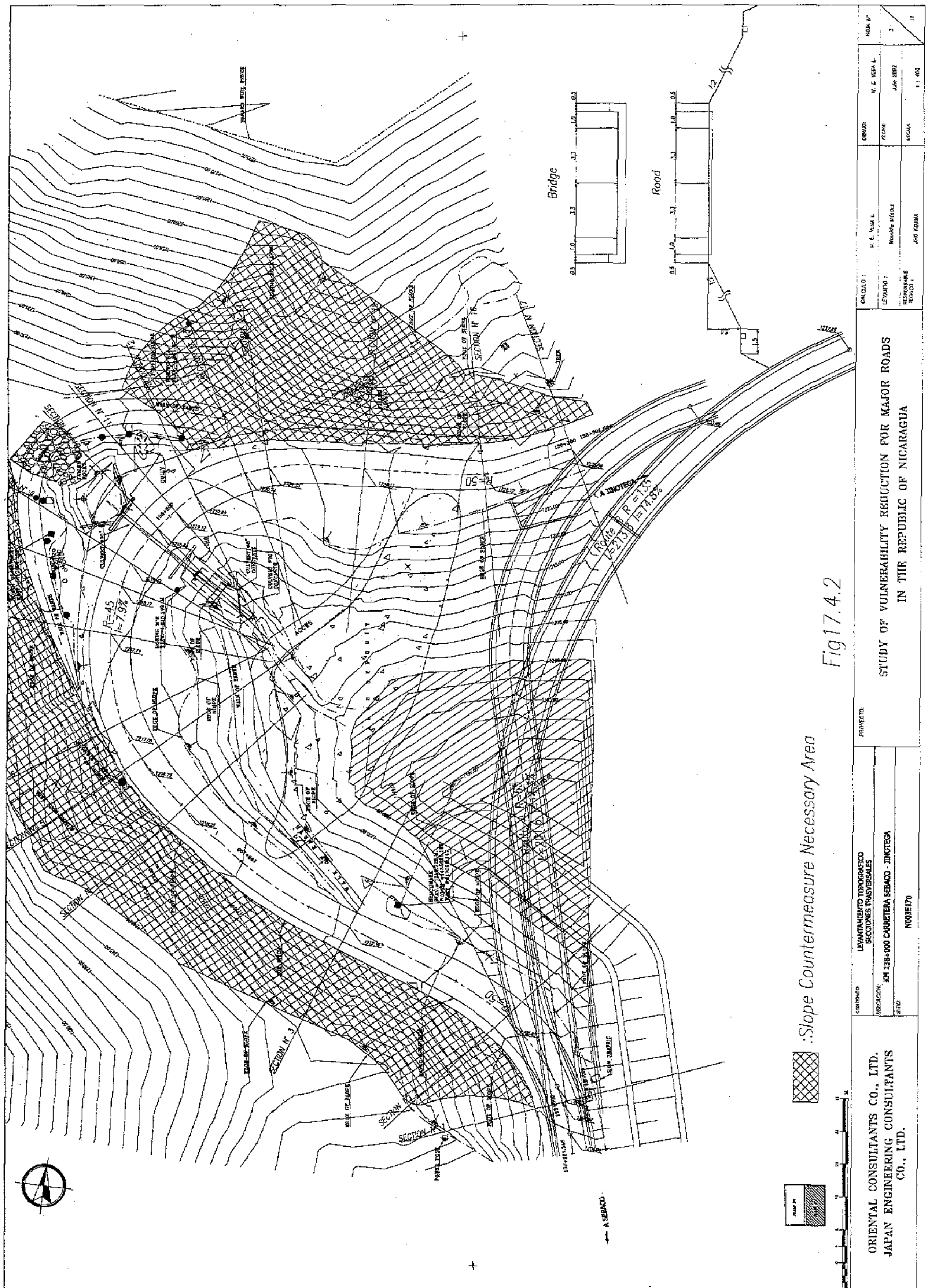


Figure 17.4.3 Route Comparison for N003E170

Table 17.4.9 Final Countermeasure Selection (1/4)

ID. No	Classification of Road Disaster	Ranking		Influence of Water	Existing Slope Grade	Existing Slope Height	Rock/Soil Character			Stability Analysis		Geometric		Special Environment Problem	Countermeasure by Primary Survey	Purpose of Countermeasure	Countermeasure made the target of the comparison
		Dry Season	Rainy Season				Rock/Soil Character	Layer Direction/Joint	Other Characters	Necessity	Safety Function	Sight Distance	Alignment				
N001A290	R.F.	70	78	Exudation of Spring Water	45-52	20-40m	Composite rock of Andesite (hard rock) Welded Tuff Tuff (soft rock)	It partly corresponds to dip slope.	There are many surface omissions. Andesite has some cracks. Wethering zone is depth 1m. Road sholder has enough width.	No	—	NP	NP	NP	- GW	- Protection of Falling Stone - Surface Drainage	- CW - GW - PN +LSR+SD
N001A280	R.F.	78	84	There is steady spring water at eight points.	45-75	7-11m	Collapsed soil of Tuff (fractured zone)	Unknown	There are sliped criff at two points. The depth 2m of tuff weathers. There is a steel tower.	Yes	High Water (Rainy Season): 0.97	NP	NP	NP	- PN	- Slope Stability - Surface Drainage	- R - GD +SD
N001A240	R.F.	84	84	Exudation of Spring Water	45-57	12-18m	Breccia Tuff (middle hard rock) Tuff (soft rock) Top part: hard rock Lower part: soft rock	Unknown	There are many falling rocks. Andesite is a block-shaped. Tuff has many crack to the depth 4m.	No	—	NP	NP	NP	- PN	- Protection of Falling Stone	- CW - GW - PN +LSR
N001B230	R.C.	72	75	Exudation of Spring Water	40-65	13-33m	Top part andesite (hard rock) Lower part Tuff (fractured zone)	It corresponds to undip slope. The crack is big, and the stone is partly loose.	There are many falling rocks. The lower part is conposed of the soil to depth 1m, and it wheters to depth 4m.	No	—	NP	NP	NP	- PN	- Protection of Falling Stone	- CW - GW - PN +LSR
N001B170	R.C.	78	81	Exudation of Spring Water at two points	42-70	13-41m	Top part andesite (hard rock) Lower part Tuff (fractured zone)	The crack is big, and the stone is partly loose.	There are many falling rocks. The lower part is conposed of the soil to depth 1m.	No	—	Set back of 3m is necessary.	NP	NP	- R+S	- Protection of Wethering	- R (Top part) - SF+S - R+CF +LSR+SD
N001B150	R.C.	76	79	Exudation of Spring Water at two points	50-70	7-13m	Top part Andesite (hard rock) Lower part Breccia Tuff	The crack is big, and the stone is partly loose.	The possibility of the falling stone is high by overhang. Internal structure is stable.	No	—	NP	NP	NP	- R+S	- Protection of Falling Stone - Protection of Wethering	- R - SF+S - R+CF +LSR+SD
N001B120	R.C.	74	76	Exudation of Spring Water at two points in rainy season	50-75	17-50m	Composite rock of Tuff (hard rock) Tuff (soft rock) Fractured zone Intrusive rock	The crack is big, and the stone is partly loose.	There are many surface omissions. Weathering of tuff is fast. Fractured zone wethers to the core.	No	—	Set back of 2m is necessary.	NP	NP	- R+S	- Slope Stability - Protection of Wethering - Countermeasure of Spring Water	- R (Top part) - SF+S - R+CF +LSR+SD

Table 17.4.9 Final Countermeasure Selection (2/4)

ID.No	Classification of Road Disaster	Ranking		Influence of Water	Existing Slope Grade	Existing Slope Height	Rock/Soil Character			Stability Analysis		Geometric		Special Environment Problem	Countermeasure by Primary Survey	Purpose of Countermeasure	Countermeasure made the target of the comparison
		Dry Season	Dry Season				Rock/Soil Character	Layer Direction/Joint	Other Characters	Necessity	Safety Function	Sight Distance	Alignment				
003B400	R.C.	72	75	There is steady spring water at two points.	33-48	8-18m	Tuff (soft stone)	The crack is big, and it is partly topring.	Tuff is composed of the soil to the depth 3m. Subsewuently is conposed of wethering zone, too. A slope is in the stable, except for the lower vertical part of the slope.	No	—	NP	NP	NP	- R+LSR	- Protection of Wethering	- SF - SF+S - SF+CF +SD
003B370	R.C.	80	80	No spring water	45-53	8-18m	Tuff (soft stone)	The crack is big, and it is partly topring.	Wethering zone of the lower part is less than 1m.	No	—	NP	NP	NP	- R+LSR	- Slope Stability - Protection of Wethering	- R (Top part) - SF+S - R+CF +SD
N003B320	R.C.	74	76	There is steady spring water at two points.	48-75	7-9m	Tuff (fractured zone)	Weathering is remarkable.	A hotel is building it at the top of the slope. The possibility that a water pipe is laid under the slope is high.	No	—	NP	NP	Avoidance of influence to the HOTEL	- R	- Slope Stability - Countermeasure of Spring Water	- CWe+V - CW+V +GD+SD
N003C230	S.S.	73	73	There is steady spring water at two points of embankment.	N:48-60 B38	N:8-16m B20-25m	Top part Tuff (soft rock, fractured zone) Lower part Tuff (hard rock, middle hard rock)	The fractured zone of tuff is 5.5m depth. There is a sliped criff.	There is drainage (Detch) on the lower part of the slope side. There is some crack on the road shoulder of embankment side.	Yes	Slope Heavy Rain: 1.01 Mitch: 0.79 Slope including road Heavy Rain: 1.17 Mitch: 1.02 Embankment Rainy Season: 1.44 (CWe) Heavy Rain: 1.00(CWe)	Set back of 3m is necessary.	NP	National Park (Renaturation)	- R+RE+CW+V	- Slope Stability - Protection of Wethering - Countermeasure of Spring Water	Cut Area - R+CF+V - GD+V +SD Embankment Area - Cwe - CWe+CW +SD+V
N003E170	D.F.	83	83	No spring water	45-62	10-22m	Top Andesite,Tuff (soft rock,fractured zone) Lower part Tuff (soft rock,fractured zone) [illegible]	There is a collapsed trace on the slope.	A weathering zone is depth 6m. Under construction of the road (paving construction). There is a small calvert.	No	—	—	It is difficult from the ground form though the improvement of the alignment is desirable.	Secuaring of existing water volume	- D	- Slope Stability - Protection of Debris Flow	Cut Area - R - R+CF +SD Debris Flow Area - NR - D
N003C150	S.S.	90	90	Though there is usually no spring water, there is it in the embankment from the step at the time of a heavy rain.	N:48-50, B35	N:13-29m, B:30-40m	Slope side Tuff (fractured zone) Road side Tuff (fractured zone)	There is a sliped criff on the slope.	There is a water way under the embankment. There is a calvert.	Yes	Slope Rainy Season: 0.94 Slope including road Rainy Season: 1.14 Heavy Rain: 1.02 Embankment Rainy Season: 1.14 (CWe) Heavy Rain: 1.01(CWe)	—	NP	Avoidance of influence to the coffee field on the top of slope.	- R+RE+CW+V	- Slope Stability - Countermeasure of Spring Water	Cut Area - R+Collapsed Soil Removal - R+GD +SD Embankment Area - Cwe - CWe+CW +SD+V
N003C140	S.S.	90	90	Though there was no especially conspicuous spring water, a water way was confirmed in the rock.	N:45-60, B30	N:6-9m, B26m	Slope side Tuff (fractured zone) Road side Tuff (fractured zone)	There is a slipe criff on the slope.	There is a water way under the embankment. There is a charch on the top of slope. There is many crack on the road sholder. Coffee is grown under the embankment.	Yes	Slope including road Rainy Season: 1.40 Heavy Rain: 0.99 Embankment Rainy Season: 1.15 (CWe) Heavy Rain: 0.99(CWe)	—	NP	Avoidance of influence to the coffee field under the embankment.	- R+RE+CW+V	- Slope Stability - Countermeasure of Spring Water (inside of rock)	Cut Area - R+Collapsed Soil Removal - R+GD +SD Embankment Area - Cwe - CWe+CW +SD+V

Table 17.4.9 Final Countermeasure Selection (3/4)

ID No	Classification of Road Disaster	Ranking		Influence of Water	Existing Slope Grade	Existing Slope Height	Rock/Soil Character			Stability Analysis		Geometric		Special Environment Problem	Counter-mea-sure by Primary Survey	Purpose of Countermeasure	Countermeasure made the target of the comparison
		Dry Season	Dry Season				Rock/Soil Character	Layer Direction/Joint	Other Characters	Necessity	Safety Function	Sight Distance	Alignment				
N005A010	R.F.	76	80	There is steady spring water at eight points, and water volume increases in the rainy season.	41-48	23-38m	Top part Talus Lower part Tuff (soft rock,fractured zone)	Unknown	- Electric line - Ditch on the slope	Yes	Adopted Back Analysis (1) Cut of 40° (Rainy Season): 1.10 Cut of 40° (Heavy Rain): 1.00 Cut of 35° (Rainy Season): 1.21 Cut of 35° (Heavy Rain): 1.12 Refer Value : Back Analysis (2) Cut of 40° (rainy Season): 1.10 Cut of 40° (Heavy Rain): 1.02 Cut of 35° (Rainy Season): 1.12 Cut of 35° (Heavy Rain): 1.10	NP	NP	Avoidance of ground water lowering of embankment side.	- R+SF+V	- Slope Stability - Protection of Falling Stone - Countermeasure of Spring Water	- R+ GD - GD+SF+S - R+CF+GD +SD+PD

Table 17.4.9 Final Countermeasure Selection (4/4)

ID No	Classification of Road Disaster	Ranking		Influence of Water	Existing Slope Grade	Existing Slope Height	Rock/Soil Character			Stability Analysis		Geometric		Special Environment Problem	Counter-mea-sure by Primary Survey	Purpose of Countermeasure	Countermeasure made the target of the comparison
		Dry Season	Dry Season				Rock/Soil Character	Layer Direction/Joint	Other Characters	Necessity	Safety Function	Sight Distance	Alignment				
N026A060	R.F.	70	78	Exudation of Spring Water from crack	53-63	9-14m	Most is Tuff (soft rock,fractured zone). The near of sholder is Andesite (soft rock). There is loose stone in the whole.	Unknown	There are many falling stones and loose stones. It is already stable.	No	—	NP	NP	NP	- R+S	- Protection of Falling Stone - Protection of Wethering	- SF+S - SF+CF +SD
N026B140	R.C.	80	80	There is steady spring water at two points of fractured zone.	50-60	11-33m	Tuff (soft rock,fractured zone) It is partly fractured zone. (W=50m)	The crack is big, and a direction isn't fixed.	Large scale stone falls in the fractured zone. 8m of the lower part is composed of granule. There is the record of the large-scale collapse at the time of the heavy rain.	Yes	Existing Rainy Season: 1.00 Low water level: 0.95 After excution Rainy Season: 1.27 Heavy Rain: 1.02	NP	NP	Avoidance of ground water lowering of embankment side.	- R	- Slope Stability - Protection of Falling Stone	- R+ GD (fractured zone) - GD+SF+S +SD+PD
N026A150	R.F.	85	87	Exudation of Spring Water	48-70	18-56m	Composite rock of Andesite,Tuff, Agglomerate The whole is alteration zone.	The crack direction isn't fixed.	There is the record of the large-scale disaster at the time of the Mitch.	No	—	Set back of 1m is necessary.	NP	NP	- R+S	- Slope Stability - Protection of Falling Stone	Continuation of B140
N026B160	R.C.	86	86	There is steady spring water at two points.	53-70	11-22m	Composite slope of Andesite, Tuff breccia It doesn't have effect to cut because it is close to the core.	It corresponds to dip slope. The crack is big, and it is partly topring.	- School zone - Bus stop	No	—	NP	NP	NP	- PN	- Protection of Falling Stone	- CW - GW - PN +LSR

17. 5 Preliminary Engineering Design for Bridge Foundation Scouring

17.5.1 Bridge-Related Factors that Affect Bridge Foundation Scouring

When a bridge pier or abutment is placed in the middle of a river, the sectional area for river flow decreases and is therefore constricted. As a result of this obstruction, water level around the upstream side of a pier rises and the water level around the downstream side of a pier decreases. This produces extremely complicated flows around the pier that contribute to scouring (see Figure 17.5.1). That is, a vertical downward flow generates a whirlpool that whips up gravel on the riverbed. The whipped-up gravel is then carried to the downstream side of a pier by opposing horizontal flows; thereby producing the phenomenon of scouring. The main bridge characteristics that greatly impact on river flow, scouring, and revetment decay are as listed below.

a) Shape of pier (shape, width, angle)
b) Abutment and revetment in front of abutment
c) Ratio of area of pier and revetment in front of abutment to the sectional area of river flow (i.e., ratio of obstruction)
d) Distance between front of abutment and pier, distance between piers (span length), free space under beam
e) Condition of revetment and preventative measures for river scouring (whether or not to carry out)
f) Characteristics of river channel (slope, width, condition of riverbed, etc.)
g) Position of bridge (relative to river width and position of river channel)
h) Others (year of bridge erection, bearing stratum, foundation type, past history of disasters, etc.)

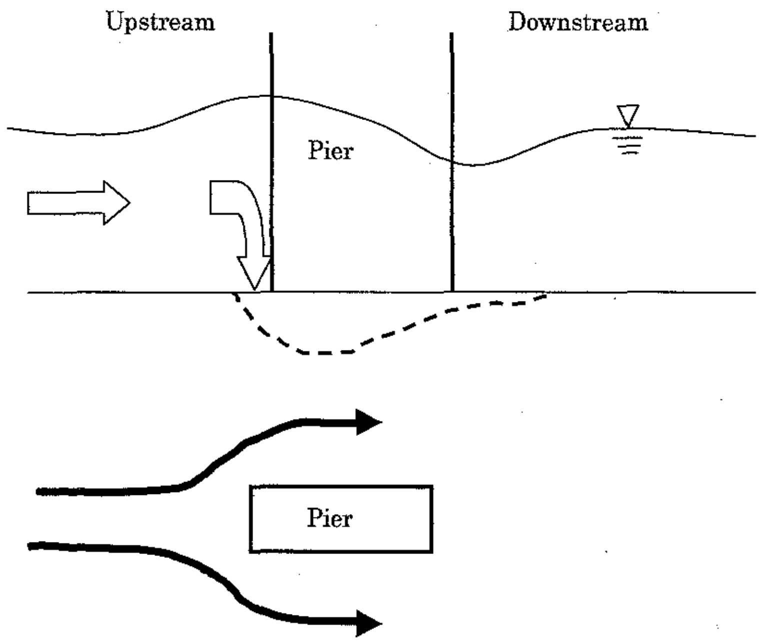


Figure 17.5.1 Change in Flow Caused by Pier

1) Shape of Pier, Obstruction Ratio of River

a) Shape of Pier

Water flow, pier width, the direction of water flows, and the sectional form of piers determine the amount of scouring that will occur.

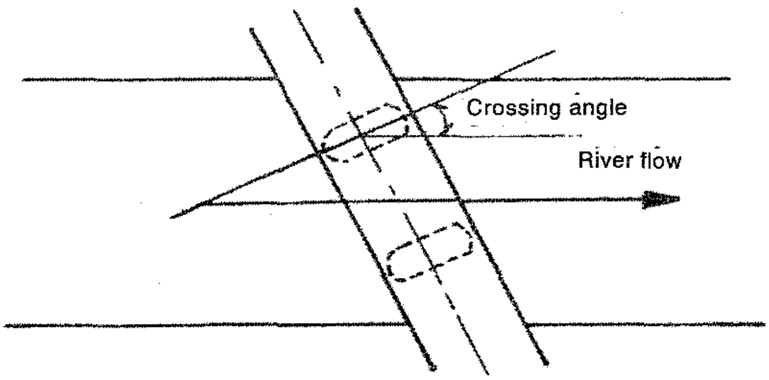
➢ **Effect of pier**

Assuming water flow is constant, the wider a pier is the greater the effect it will have.

➢ **Effect of the angle at which the flow of water meets the longitudinal axis of a pile**

An example of the effect of the angle at which the flow of water meets the longitudinal axis of a pile is as follows:

> The amount of scouring in the case of a 10° angle would be greater than that in the case of 0° angle, with scouring occurring at the position more down-stream to the upstream head of the pier. In the case of a 20° angle, scouring would be greatest at the upstream head of a pier, with the range of scouring tending to widen greatly. Note that the greater the angle at which the flow of water meets the longitudinal axis of a pile the larger the amount of scouring that will occur.



➢ **Effect of Shape**

The comparison of the amount of scouring that results from differences in pier shape, which was researched by Laursen, is as described in Table 17.5.1. This table assumes that the direction of water flow is the same as that of the pier axis. As the results of the table indicate, scouring depth tends to become shallower when the sectional form of a pier is rectangular than if it is a semicircular. Moreover, scouring for a semicircular pier would be less than that of a pier elliptical in shape.

On the other hand, when the direction of water flow is not the same as that of the pier axis, the effect of the angle between pier and water flow becomes greater and the sectional form of a pier more important (Figure 17.5.2). Therefore, in the case of the natural river like in Nicaragua, a semicircular or cylindrical pier seems more appropriate.

In the case of a pile-bent-type pier and rigid-frame pier, driftwood is easily snagged, resulting in a greater obstruction to the river and more complicated water flows. Especially, the pile-bent-type pier will generate whirlpool flows during flooding that will produce abnormal scouring around piers and appropriate countermeasures should therefore be taken. In the case of a rigid-frame pier, it is advisable to make the sectional form unity by installing a screen bulkhead (Figure 17.5.3).

Table 17.5.1 Correction Factor Concerning Front-end Shape of Pier

Shape of Front	Ratio of length to width	Ks
Rectangle		1. 00
Semicircle		0. 90
Oval	2 : 1	0. 80
	3 : 1	0. 75
Lens-shaped	2 : 1	0. 80
	3 : 1	0. 70

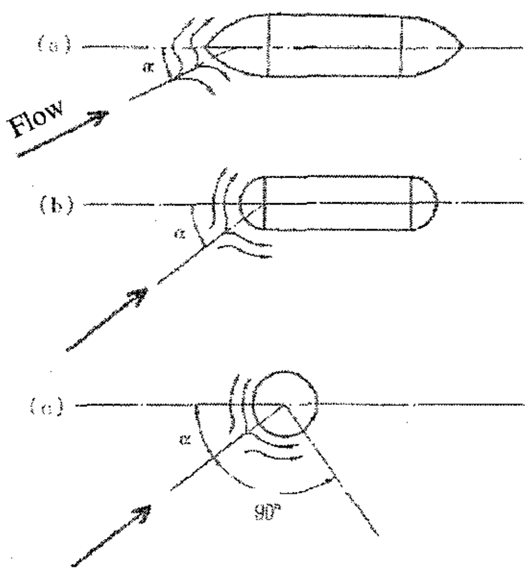


Figure 17.5.2 River Flow & Pier Shape (When Flow and Direction of Pier Axis Different)

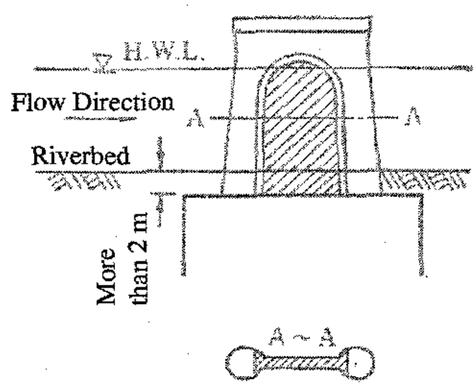


Figure 17.5.3 Installation of Bulkhead

b) River Obstruction Ratio

The river obstruction ratio is the ratio of the total sectional area of piers to the sectional area of river flow at a 90° angle (see Figure 17.5.4). The bigger the obstruction ratio, the smaller the sectional area for water flow, resulting in a constricted channel and quicker scouring due to faster water flows. For bridges with a river obstruction ratio of 7% or more, substantial re-inforcement against scouring is required.

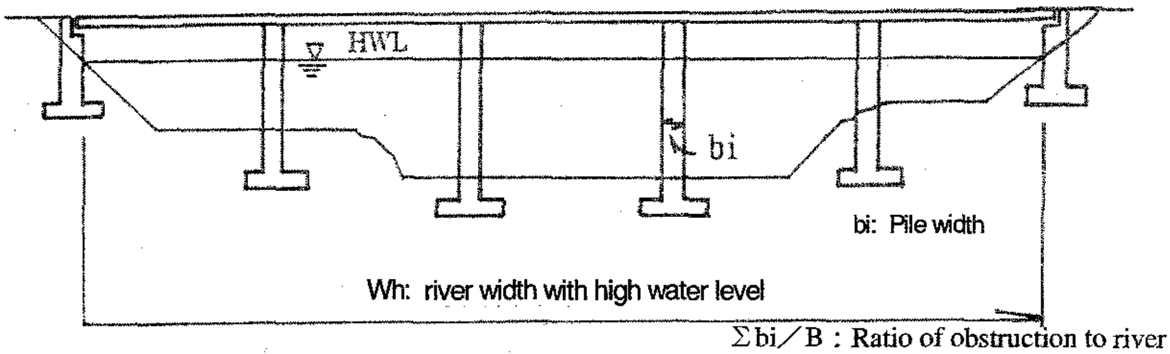


Figure 17.5.4 Calculation Method for River Obstruction Ratio

2) Abutment and Revetment in Front of Abutment

In order to avoid the obstruction of river flows, abutments should not be constructed inside the sectional area of river water flows. This means that it is advisable to locate abutments outside of river revetments. If an abutment is located inside the sectional area of a river water flow, or if the abutment sticks extends into the inner side of a river revetment (Figure 17.5.5), the water flow will become chaotic and scouring will result around the pier.

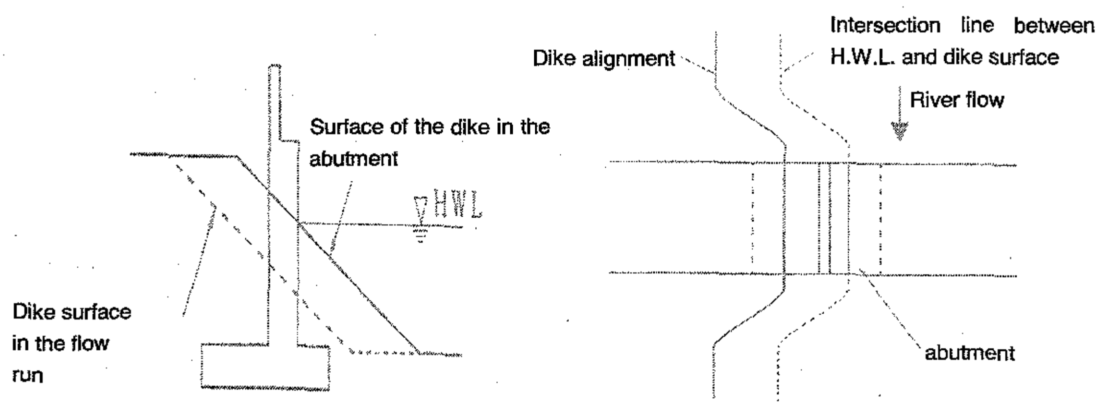


Figure 17.5.5 Case where Abutment Extends into River

3) Distance Between Front-end of Abutment & Pier, Distance Between Piers (Span Length), Free Space Under Beam

In the case of flooding, driftwood, collapsed houses, etc. can flow down and be caught at bridges due to insufficient space. In such cases, not only abnormal scouring but overflows can occur, leading to the decay of revetments and the back of abutments. Therefore, the following two items must be in mind when designing a bridge.

a) distance between front-end of abutment and center of pier, or distance between centers of piers (span length)
b) distance between bottom of bridge girder and flood water level

At the bridge which does not satisfy these 2 conditions, the possibility of trouble occurrence is very high, and it is necessary to take substantial countermeasure in advance.

The following is the abstract of above-mentioned 2 points. Those numbers have been determined based on the observation and experiences over a long period in Japan. Except for the plain in the side of Caribbean, the rivers in Nicaragua are characterized as short and steep, and the rainfall is 1500-2000 mm. These natural conditions are similar to those in Japan. The climate zone of Japan is Temperate Zone, on the other hand, that of Nicaragua (except for plain along the Caribbean) is Savanna type. Although there is some differences in vegetation between 2 countries, there is almost no differences in the size of trees between 2 countries. Therefore, there would be no big problem in Nicaragua if the conditions satisfied the following numeric values.

However, it is important to collect and accumulate information concerning to these matters and to figure out standard specific to Nicaragua from now on.

a) Distance Between Front-end of Abutment & Pier, Distance Between Piers (Span Length)

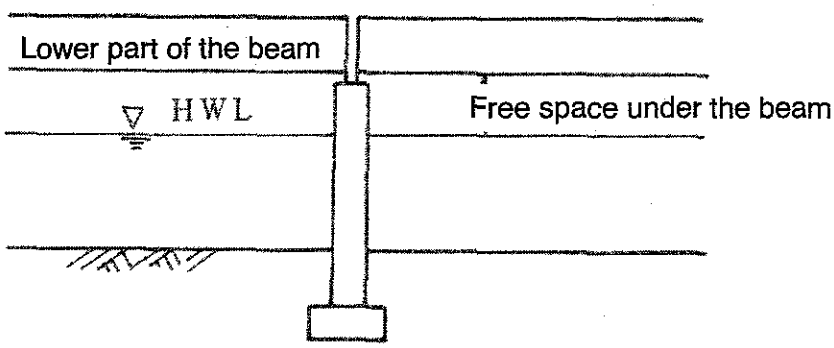
Span length means the distance between the centerlines of adjacent piers inside a river channel. This distance is supposed to be measured on the river-crossing plane perpendicular to the direction of flood streams (see Figure 17.5.6). Span length is determined by factors including route importance, flow velocity, river width, etc. (see Figure 17.5.7).

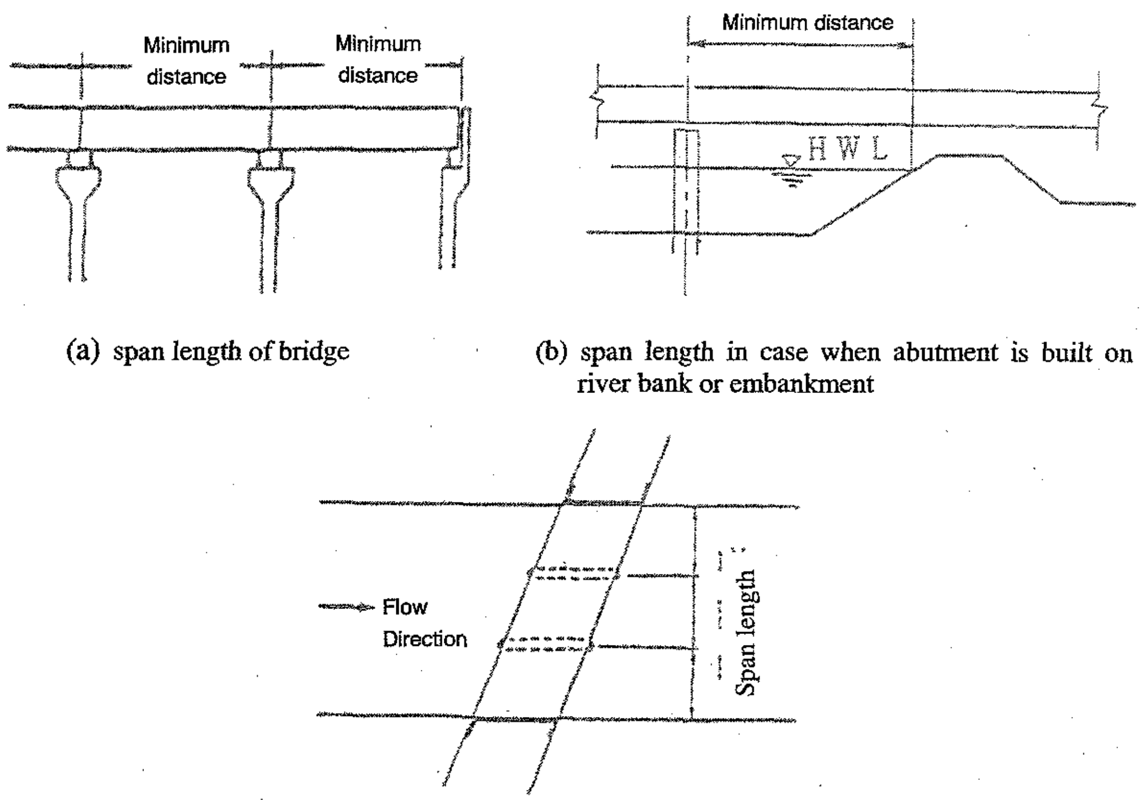
b) Free Space under Beam

It is advisable to keep the distance shown in Table 17.5.2 between water level and the bottom of a girder. Despite the fact that the numeric values shown in the table are only a guideline, it is necessary to take much care for a distance of less than 0.6 m.

Table 17.5.2 Free Space under Beam

Q (m^3/sec)	Q<200	200≦Q<500	500≦Q<2000	2000≦Q<5000
Free space under beam (m)	0.6	0.8	1.0	1.2





(a) span length of bridge

(b) span length in case when abutment is built on river bank or embankment

(c) span length in case of skew bridge

Figure 17.5.6 Span Length

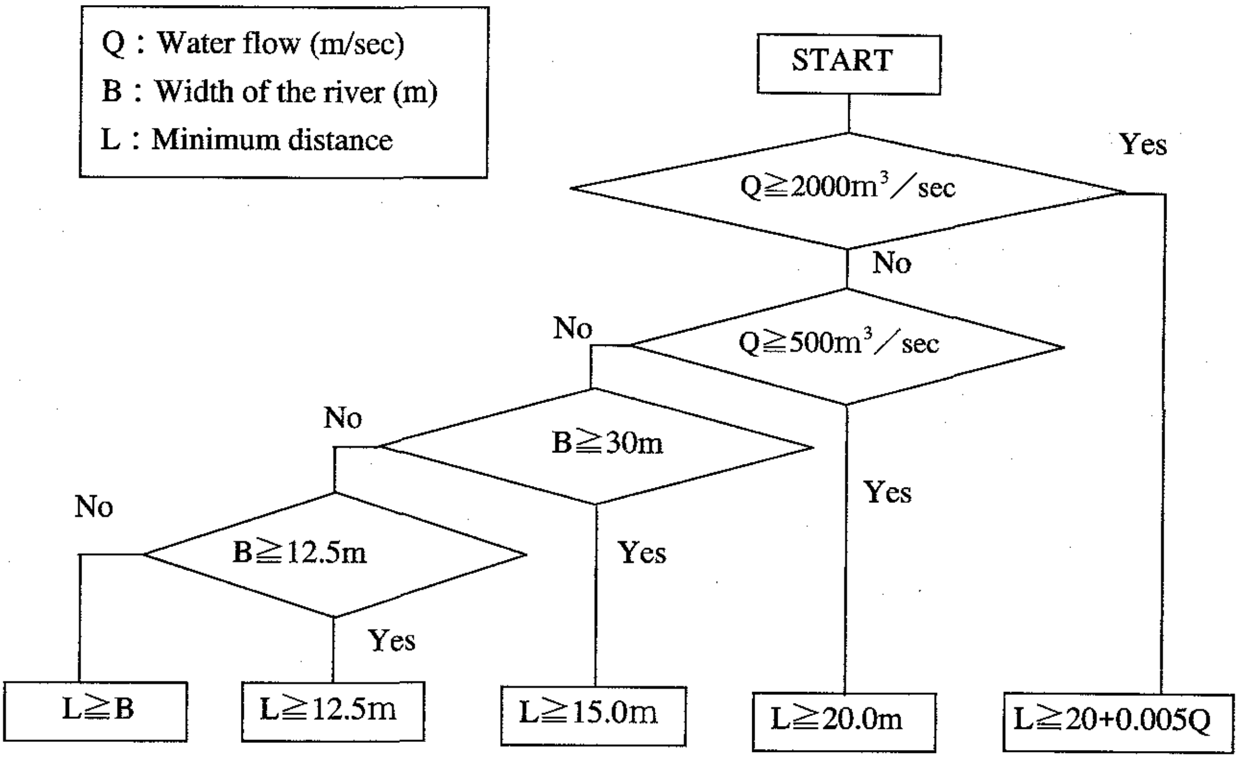


Figure 17.5.7 Minimum Distance Between Piers and between Pier & Abutment(Span Length)

4) Condition of Revetment & Preventative Measures for River Scouring

Water flow, which becomes complicated due to the existence of a pier and/or abutment, can have an adverse effect not only on the riverbed but on the revetment near the abutment as well. For that reason, the position and size of a guard around a pier and/or front-end of an abutment are important. It is advisable to satisfy the conditions shown in Figure 17.5.8 and Figure 17.5.9 when installing a guard. As for preventative measures for scouring around piers, it is advisable to satisfy the calculated values shown in 3).

5) Characteristics of River Channel(Slope, Width, Condition of Riverbed, etc.)

In order to properly evaluate the possibility of river scouring, it is also important to consider the characteristics of a river channel. In addition to maximum flow and velocity derived from hydrological analysis, the slope of a water channel, width, etc. are also elements closely related with river scouring. For that reason, it is important to collect data through a natural condition survey (which is most effective rivers are at their HWL).

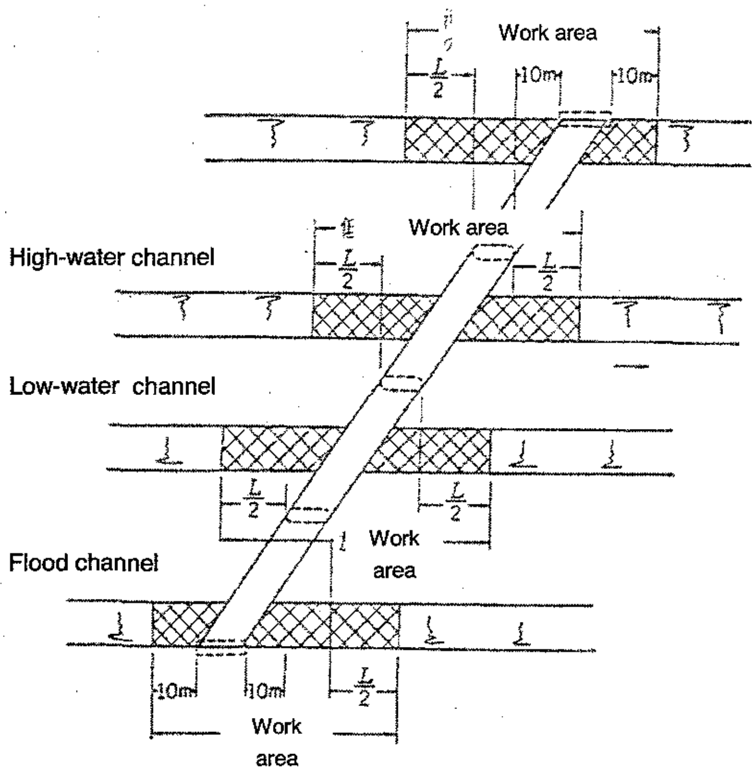


Figure 17.5.8 Distance of Guard to Protect around Bridge

L=minimum span length (m): minimum distance between abutment and pier, and between piers based on procedure

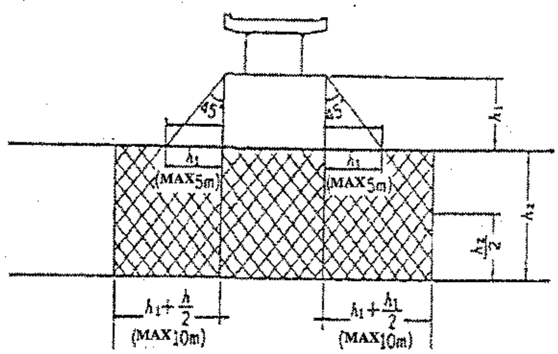


Figure 17.5.9 Size of Guard to Protect Riverbank below Bridge

6) Position for Bridge Installation

As described in **1) - 5)** above, the existence of piers/abutments in a river complicates river flow and causes scouring. Therefore, from the viewpoint of planning disaster prevention measures for rivers, it is important to observe and record this relationship and to grasp the correlation between river characteristics (such as riverbed formation and soil composition) and the scouring of bridge piers/abutments (see Figure 17.5.11). In addition, it is important to compare the estimates for river scouring with the formulas shown in Section 17.6 with actual values in order to understand the causes of scouring better.

Furthermore, it is also important a bridge be substantial longer than the width of a river (Figure 17.5.10) and that the location of a bridge not become inappropriate due to potential river alignment changes (Figure 17.5.11). Therefore, it is important to observe and record changes not only around piers and abutments but for the entire river channel as a whole in order to ensure the most suitable design for a bridge.

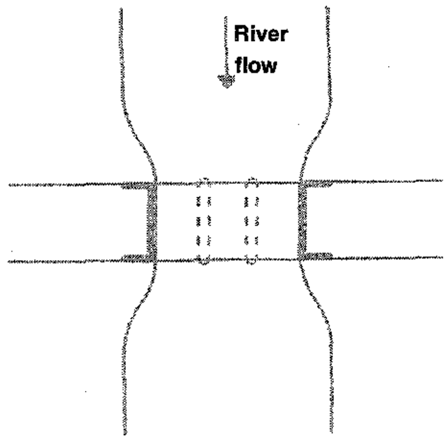


Figure17.5.10 Case where River Width near a Bridge is Narrower than Upstream/Downstream River Width.

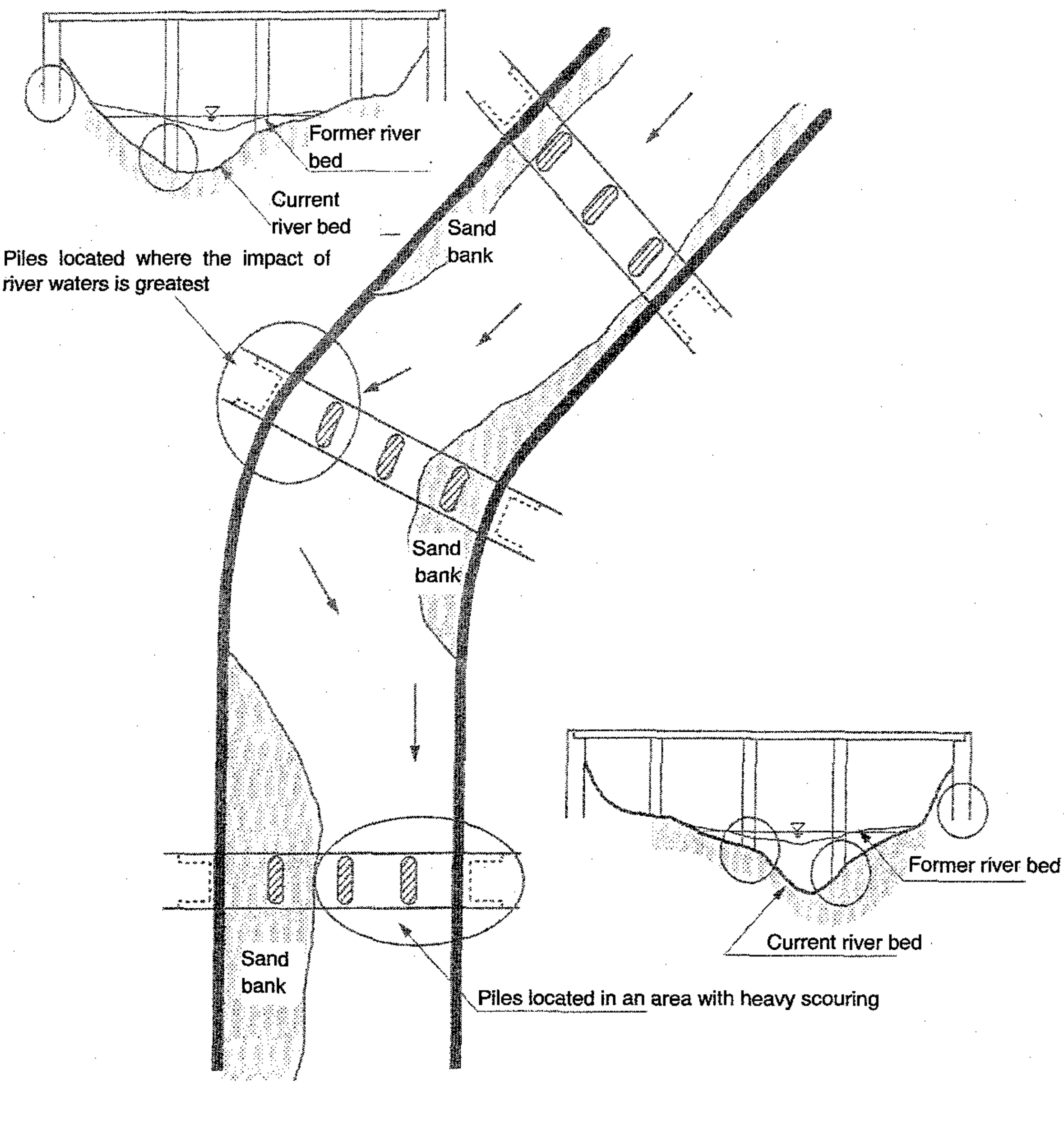


Figure 17.5.11 Relationship between River Condition & Bridge Foundation Scouring

7) Others (Year of Erection, Bearing Stratum, Foundation Type, Past History of Disasters, etc.)

In addition to the factors mentioned so far, the year of bridge erection, bearing stratum, foundation type, past history of disasters, etc. are also useful information. For example, if a bridge is quite old, the level of a riverbed might have become lower due more to the effects of time than scouring. Again, by reviewing the past history of disasters that have taken place around a bridge site, it is possible to detect potential problems. Such a review will make it possible to accurately compare estimated and actual levels of flooding.

Furthermore, bearing stratum under piers is also an important consideration for scouring countermeasures. If the bearing stratum under a pier is bedrock and if pier embedment is substantial (more than 2m), the effects of scouring would be insignificant. However, if the bearing stratum is gravel, substantial embedment would not guarantee a situation free of worry. This is because the upper stratum is often loose and it is therefore necessary to be cautious about the bearing stratum even if the pile foundation is substantially embedded.

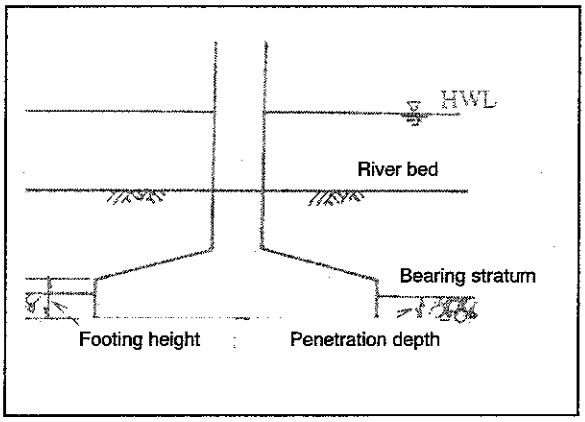


Figure 17.5.12 Embedment of Spread Foundation into Bearing Stratum

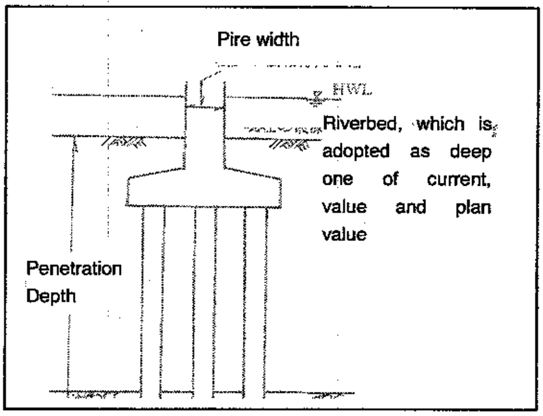


Figure 17.5.13 Embedment of Pile Foundation, Caisson Foundation, and Steel-Pipe-Sheet Pile Foundation into Bearing Stratum

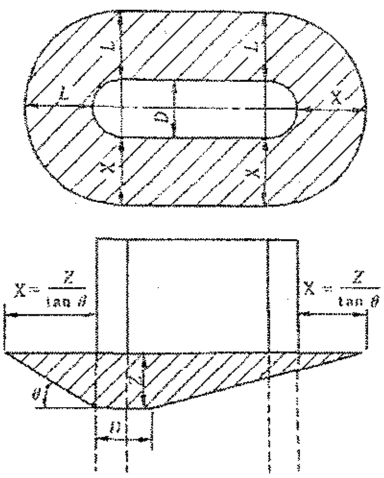
17.5.2 Estimation of Scouring

By estimating the amount of scouring around piers based on the results of the hydrological survey, it is possible to take disaster preventative measures in advance. The depth of scouring can be estimated based on the results of experiments conducted by the National Institute for Land and Infrastructure Management (formerly the Public Works Research Institute) of the Ministry of Land, Infrastructure, and Transport (see 16.2.2).

Of the bridges considered in this Study, those that have piers are the Junquillal Bridge, LasChanilas Bridge, Tacapali Bridge, San Juan de Dios Bridge, and La Banderita Bridge. Of these, those detected with scouring are Junquillal Bridge, LasChanilas Bridge, and Tacapali Bridge. Table 17.5.3 shows the results of the estimation and actual measurement.

Table 17.5.3 Estimation of Scouring

River Name		UNIT	Junquillal	Las Chanil-las	Inali	Tacapari	El Guayacan	San Juan de Dios	La Banderita
Width of river W :		m	29.3	62	64	109	17.5	17.9	31.6
Width of pier D :		m	0.4	0.7	0.8	1	0.9	0.4	1.1
Discharge of High water level Q :		m3/s	246.28	668.61	579.58	886.75	149.08	67.22	60.12
Average level of road surface		m	457.3	822	638.2	299.62	614	96.4	226.7
Average level of riverbed		m	453.65	815	631.27	292	609.6	94	217.8
of High water level in flood		m	458.01	817.765	634.27	295.952	614.59	96.25	220.47
Mean water depth in flood ho :		m	4.36	2.765	3	3.952	4.99	2.25	2.67
Average grain diameter of riverbed materials dm :		mm	0.5	6	13	10	15	1	3
ho/D		-	10.90	3.95	3.75	3.95	5.54	5.63	2.43
Fr = (V/(W·ho))/√(g·ho) =		-	0.29	0.75	0.56	0.33	0.24	0.36	0.14
ho/dm		-	8720.0	460.8	230.8	395.2	332.7	2250.0	890.0
Z/D		-	1.48	1.8	1.68	1.45	1.2	1.55	0.8
Z		m	1.776	2.16	2.016	1.74	1.44	1.86	0.96
Angle of repose ?		Deg	31.0	34.0	40.0	40.0	40.0	31.0	32.0
tan?		-	0.60	0.67	0.84	0.84	0.84	0.60	0.62
X=Z/tan?		m	2.96	3.20	2.40	2.07	1.72	3.10	1.54
Result of site survey	Width(X)	m	3.0	3.0	-	2.0	-	-	-
	Length(L)	m	4.0	4.0	-	2.0	-	-	-
	Depth(Z)	m	0.7	0.8	-	1.0	-	-	-



X : Horizontal distance of the range of scouring
Z : Maximum depth of scouring
θ : Angle of repose
D : Width of pier

17.5.3 Selection Process for Countermeasures and a Concrete Example

The type of countermeasure to be applied will differ depending on the location of scouring and the purpose. In addition, the measure to be applied depends on whether a permanent or temporary structure is to be built. Expected scouring locations are as follows:

1) Around piers
2) Around abutments
3) Embankment for approaches

The selection process for scouring countermeasures is shown in Figure 7.2.9. Note that a temporary countermeasure should be applied when the present amount of scouring is not large and there is a plan to replace the existing bridge with a new bridge in several years time (i.e., within 5 years). On the other hand, a permanent structure is advisable for the following situations.

a) Large amount of scouring is detected.
b) The sectional area of the river is insufficient (e.g., bridge is submerged almost every year).
c) River velocity is fast.
d) The relative location of the bridge has become inappropriate due to a change in the alignment of the river channel.

1) Scouring Countermeasures for Piers

In consideration of the materials used to prevent scouring around piers, the possible alternatives are as shown in Table 17.5.5. Table 17.5.6 shows the applicability of each measurement by bridge site.

When rubble and/or concrete block are used to prevent scouring, the weight and size of those materials must be considered in relation with the velocity of water flow. The reference values for this relationship are shown in Figure 17.5.14 and Table17.5.4.

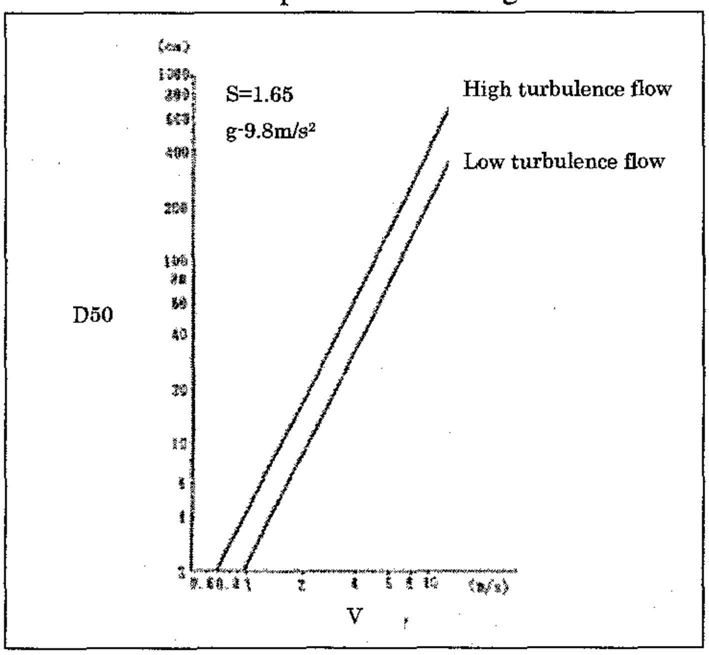


Figure 17.5.14 Relation between Size of Rubble and Velocity of Water Flow

Table 17.5.4 Relation between Block Weight and Velocity of Water Flow

Shape	Weight of Block (ton)	Velocity of water Flow (m/s)
	1.0	2.5
	2.0	3.0
Flat Type	3.0	3.5
	4.0	4.0
	5.0	4.5
	6.0	5.0

Table 17.5.5 Comparison of Prevention Measures for Foundation Scouring

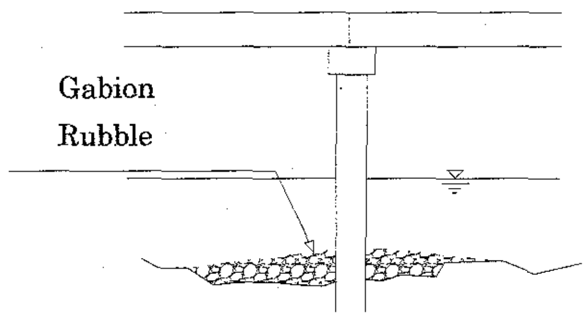
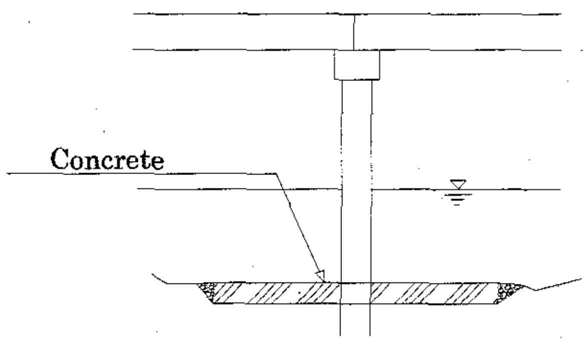
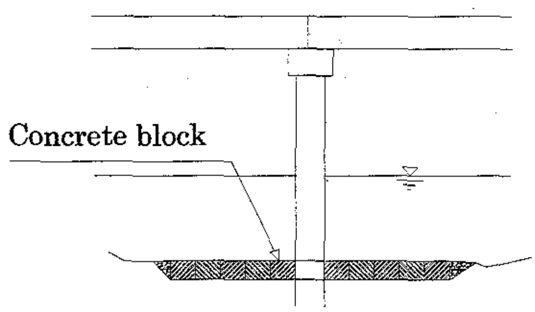
Material	Illustration	Remarks
Rubble and gabion		This measure is for temporary works and for works in rivers with slow velocity. Economically efficient. Facility for construction is simple and easy (manual labor only is basically sufficient). The advantage of rubble is that it can change its form in response to differential settlement of the riverbed if the foundation is soft. Maintenance is necessary.
Protection by the Concrete		This measure is applied at sites with fast flows and strong riverbed foundations. This measure is inappropriate for sites with soft riverbed foundations because the structure might collapse due to differential settlement. Because, this measure requires the pouring of concrete on site, it is impossible to execute in the rainy season.
Protection by precast concrete block		By changing the size of concrete block in accordance with the velocity of water flow, this measure can be applied to all kinds of rivers. Because precast concrete is applied, construction can be implemented at any time except during floods. Maintenance is not necessary. This measure can bear small differential settlement.

Table 17.5.6 Countermeasure Applicability by Bridge

Name	Rubble Gabion	Concrete	Concrete Block	Explanatory Remarks
Junqillal	A	C	C	It is predictable that the settlement will occue due to the soft riverbed. The velocity of water flow is slow. The river always has water flow.
San Nicolas	A	C	C	The velocity of water flow is slow. The river always has water flow.
Las Chanillas	C	B	A	The velocity of water flow is fast.
San Ramon	A	C	C	It is predictable that the settlement will occue due to the soft riverbed.
Inali	C	B	A	The velocity of water flow is fast.
Tapacali	C	B	A	The velocity of water flow is rather fast. The river always has water flow.
El Guayacan	A	A	A	The velocity of water flow is slow. There is a season when the water flow in the river dissapears.
Solis	C	A	B	The velocity of water flow is fast. The riverbed is consisted of soft rock. The block is not economical because the width of river is narrow.
Papalon	C	A	B	The velocity of water flow is fast. The riverbed is consisted of soft rock. The block is not economical because the width of river is narrow.
San Juan de Dios	A	C	C	It is predictable that the settlement will occue due to the soft riverbed. The economical advantage is excellent.
La Banderita	A	C	C	The velocity of water flow is relatively fast. The economical advantage is excellent.

A : Advisable measure
B : Applicable measure
C : Measure difficult to apply

2) Countermeasure against Scouring around Abutments

Basically, it is advisable to execute scouring countermeasures for the front-end of abutments as shown in Figure 17.5.15 and Figure 17.5.16 In the case that the height of the water level is more than 5 meters, the countermeasure shown in Figure 17.5.15 shall be carried out.

As for scouring countermeasures around abutments, this shall be carried out at abutments with a height of more than 3 meters.

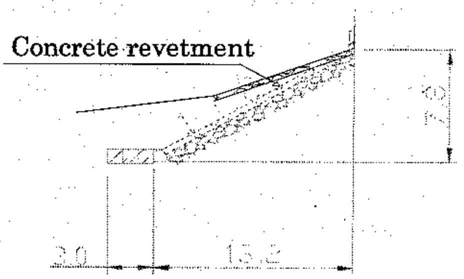


Figure17.5.15 Revetment by Concrete (1:2)

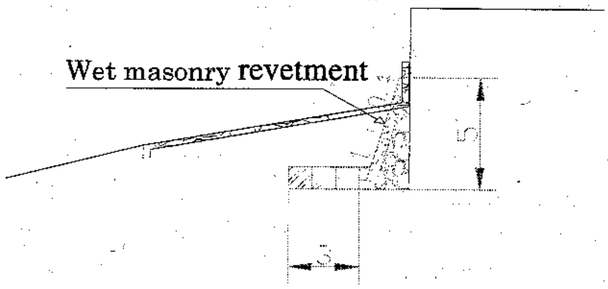


Figure17.5.16 Revetment by Concrete (1:0.4) H≦5m

3) Dike Approaches

When a dike approach is extends into a river, it is advisable to protect the slope of the dike approach with concrete as shown in Figure 17.5.17. Then, using gabion, a countermeasure to protect the downstream riverbed shall also be carried out.

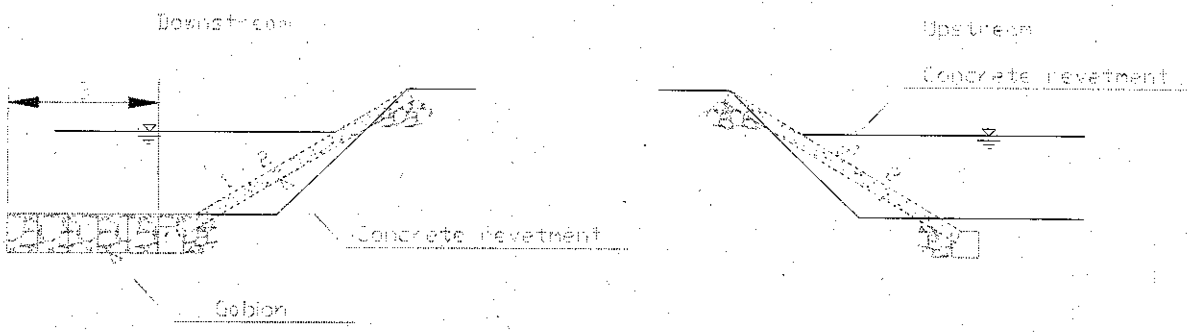


Figure 17.5.17 Protection for Dike Approaches (Case where Dike Approach Extends into River)

17.5.4 Disaster Prevention Spot Issues & Countermeasures

The issues that should be considered for each disaster prevention spot, which is based on a review of historcial and current data, and the appropriate countermeasures are as shown in Table 17.5.7.

Table 17.5.7(1) Disaster Prevention Spot Issues & Countermeasures (1/2)

Name of bridge			Junquillal	San Nicolas	Las Charnillas	San Ramon	Inali	Tapacali
Name of route			NIC.1	NIC.1	NIC.1	NIC.1	NIC.1	NIC.1
Station			113+190	135+640	150+330	151+850	226+890	233+245
Year of construction			1956	1957	1958	1957	1954	1954
Past history of disasters			Partial destruction	-	Partial destruction	-	Partial destruction	some damage
Bridge type	Length of side span		Three simple concrete slabs bridge	simple steel bridge	Prestressed concrete, simply supported girder bridge	Prestressed concrete, simply supported girder bridge	3 spans continuous steel plate bridge	Simple steel plate beam
	Length of center span			-	Simple steel plate bridge	-		3 spans continuous steel plate bridge
Foundation type *			Pile	Direct	Spread foundation	Spread foundation	Spread foundation	Spread foundation
Geological characteristics of bedding			Weathered tuff	Weathered andesite	Weathered tuff	Weathered tuff	Weathered andesite	Weathered tuff
Bridge length (span length)		m	29.3 (9+9+9)	18.86 (17.6)	62.0 (17.8+24.0+17.8)	15.5 (14.5)	64.0 (19.0+24.0+19.0)	109.0(17.8+21.3+26.7+21.3+17.8)
Obstruction Ratio		-	4.5	-	1.6	-	11.0	8.8
Width of river	upstream	m	19.0	17.0	54.5	9.8	84	90
	downstream	m	25.0	13.5	41	9.3	95	70
Gradient of river		%	0.14	2.42	1.7	0.5	0.95	0.3
Riverbed conditions		m	Cohesive soil	Gravel	Gravel	Sandy soil	Gravel	Gravel
Roughness co-efficient		-	0.027	0.02	0.028	0.045	0.028	0.028
Catchment area		km^2	49.8	6.1	114.6	2.7	84.8	147.11
Co-efficient of discharge		-	0.46	0.42	0.6	0.48	0.59	0.62
Rainfall Intensity	100years	mm/h	48.1	117.7	42	117.7	50	45
Flood flow		m^3/s	306.1	83.77	802.33	42.38	694.94	1266.8
Velocity of flow		m/s	1.91	1.84	5.03	2.54	4.92	2.9
Standard span length		m	12.5	12.5	20.0	9.8	20.0	20.0
Free space under beam		m	0	3.3	2.3	2.7	1.9	1.3
Stability	abutment	-	75	45	65	30	90	75
	pier	-	80	-	60	-	100	70
Condition of scouring of foundation	abutment	-	70	100	70	100	50	100
	pier	-	90	-	90	-	50	90
Problems			Inadequate river sectional area Short length of span	Steep gradient of river	Relatively steep gradient of river High velocity of river flow Inadequate span length as for the side span part	Inverse effect from the trace of the former old bridge	The length of bridge is short, compared with the width of river The obstruction is large in river sectional area. The distance between the revetment in front of abutment and pier is short. High velocity of river flow	The obstruction is large in river sectional area. The distance between the revetment in front of abutment and pier is short.
Proposed countermeasures			(i) Total replacement to new bridge (ii) In order to increase the sectional area of river, to build the culverts at the upstream and downstream parts	(i) To raise the level of riverbed. in order to protect riverbed at the same time (ii) To implement spur dyke in order to decrease the velocity of river flow	(i) To decrease velocity of river flow by building weir (ii) To implement countermeasure against scouring around piers (iii) To remove revetment in front of abutment, and to widen the sectional area of river flow	(i) To remove the trace of former old bridge (ii) Implement groundsel	(i) To remove revetment in front of abutment, and to widen the sectional area of river flow (ii) To build spur dyke, in order to prevent direct water current from hitting bank of approach.. (iii) To decrease velocity of river flow by implementing spur dyke (iv) To protect scouring of foundation around piers	(i) To remove revetment in front of abutment, and to widen the sectional area of river flow (ii) To protect scouring of foundation around piers

Table 17.5.7(2) Disaster Prevention Spot Issues & Countermeasures (2/2)

Name of bridge			El Guayacan	Solis	Papalon	San Juan de Dios	La Banderita
Name of route			NIC.3	NIC.26	NIC.26	NIC.26	NIC.26
Station			119+050	107+533	108+154	156+785	170+952
Year of construction			1945	1963	1963	1965	1966
Past history of disasters			Wind destroyed	-	-	-	-
Bridge type	Length of side span		Three concrete arched bridge	Simple concrete slab bridge	Simple concrete slab bridge	Two simple concrete slabs bridge	Simple concrete slab bridge
	Length of center span						Prestressed concrete, simply supported girder bridge
Foundation type *			Spread foundation	Spread foundation	Spread foundation	Spread foundation	Spread foundation
Geological characteristics of bedding			Weathered tuff	Weathered andesite	Weathered tuff	Weathered andesite	Weathered tuff
Bridge length (span length)		m	17.5	7.2 (4.6)	5.1 (3.5)	17.9 (7.5+7.5)	31.6 (6.6+15.4+6.6)
Obstruction Ratio		-	27.0	-	-	2.5	6.7
Width of *river*	upstream	m	38.8	6.2	6.8	17.9	19.3
	down-stream	m	42.0	5.8	7	19.2	18
Gradient of river		%	1.3	2	2.2	1	1.79
Riverbed conditions		m	gravel	sand	sand	sand	gravel
Roughness co-efficient		-	0.027	0.016	0.016	0.027	0.027
Catchment area		km^2	28.3	0.8	0.6	9	7.7
Co-efficient of discharge		-	0.49	0.45	0.46	0.44	0.46
Rainfall intensity	100years	Mm/h	48.1	123.4	123.4	73.8	73.8
Flood flow		M3/s	185.29	12.34	9.46	81.19	72.6
Velocity of flow		m/s	1.07	2.37	2.76	1.07	1.26
Standard span length		M	12.5	6.2	7	12.5	12.5
Free space under beam		M	0	3.4	3.0	0	5.2
Stability	abutment	-	100	75	70	75	50
	pier	-	90	-	-	65	50
Condition of *scouring of* foundation	abutment	-	100	100	90	90	100
	pier	-	90	-	-	20	20
Problems			Inadequate sectional area of river flow *Short span length* Large ratio of obstruction *The location of* bridge doesn't correspond to the that of river.	Steep gradient of river	Steep gradient of river *A little bit short* length of bridge, compared with the widths of the upstream and down-*stream river channel.*	Inadequate sectional area of river flow *Short span length* The accumulation of earth and sand is considerable.	A little bit steep gradient of river *The distance between* the pier and the foundation of abutment is short. Short length *of side* span
Proposed countermeasures			(i) Total replacement to new bridge (ii) Improve the river channel (iii) Revetment work of approach part	(i) To raise the level of riverbed. in order to protect riverbed at the same time (ii) To implement spur dyke in order to decrease the velocity of river flow (iii) To decrease velocity of river flow by building weir (iv) Total replacement to new bridge	(i) Total replacement to new bridge (ii) To raise the level of riverbed. in order to protect riverbed at the same time (iii) To implement spur dyke in order to decrease the velocity of river flow (iv) To decrease velocity of river flow by building weir (v) Total replacement to new bridge	(i) Total replacement to new bridge (ii) To dredge the riverbed in order to decrease level of the riverbed	(i) To build revetment in order to protect foundation of abutment (ii) To limit the sectional area of river to the space between piers by backfilling both side of river channel up to the piers

17.6 Selection of Spot Specific Countermeasures

17.6.1 Selection of Slope Damage Prevention Countermeasures

1) General

The selection of slope damage prevention countermeasures is carried out based on the results of Table17.4.9, with the selection methodology shown in Figure 17.6.1.

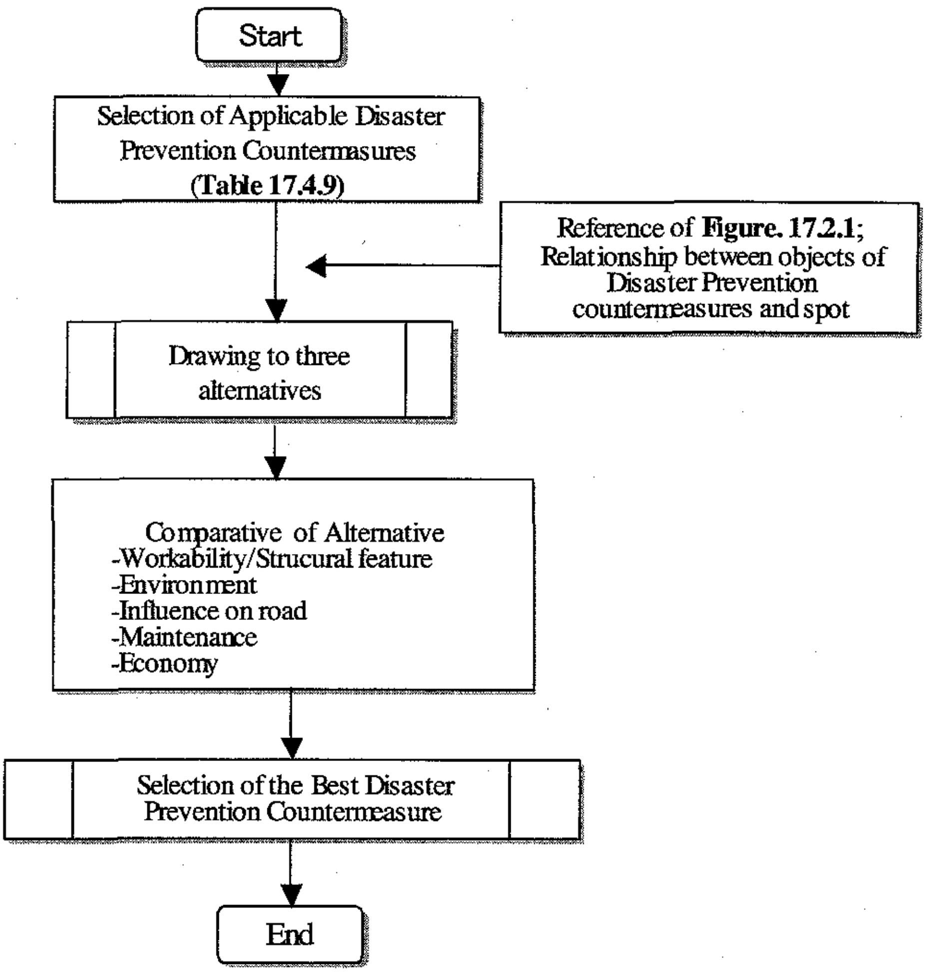


Figure17.6.1 Flow Chart for the Selection of Disaster Prevention Countermeasures

2) Selection of Alternative Countermeasures

Applicable disaster prevention countermeasures are selected based on results previously described (refer to Table17.4.9).
Alternatives, of which there are three, are make up of a combine of the selected disaster prevention countermeasures. The results of a comparative study of the preventive countermeasure are shown in Table 17.6.1- Table 17.6.5.

3) Selection of Disaster Prevention Countermeasures

The best disaster prevention countermeasures are selected after a comparative examination of three different alternatives. The comparative analysis is carried out using the items listed below. The analysis is qualitative in nature and applies the symbols ◎,○,△: ◎ is excellent, ○ is normal, and △ is poor. Based on this, prioritization using the numerals 1, 2, and 3 is performed, with 1 being the best and 3 the worst.

- Workability/Structural features
- Environment
- Influence on road
- Maintenance
- Economy

Table 17.6.1 Countermeasure Alternatives for NIC.1

IDNo			N001A290	N001A280	N001A240	N001B230	N001B170	N001B150	N001B120
Distance			80.9	73.2	168.4	168.8	171.3	175.0	176.2
Purpose of Countermeasure			R.F Seepage warter	R.F Stability of Slope Seepage water	R.F	R.C	R.C Weathering	R.C Weathering	R.C Stability of Slope Weathering Seepage water
1) Increase of stability	①	Widening Embankment							
	②	Counterweight							
	③	Retaining Wall							
	④	Crib Work		④					
	⑤	Stone Masonry							
2) Removal of unstable material	⑥	Cutting		⑥			⑥	⑥	⑥
	⑦	Removal	⑦		⑦	⑦			
	⑧	Splitting	⑧		⑧	⑧			
3) Reduction of pore water pressure	⑨	Surface Drainage	⑨	⑨			⑨	⑨	⑨
	⑩	Horizontal Drainage		⑩					⑩
	⑪	Vegetation		⑪			⑪		⑪
4) Prevention of erosion and weathering	⑪	Vegetation					⑪	⑪	⑪
	⑫	Shotcrete					⑫	⑫	⑫
	⑨	Surface Drainage					⑨	⑨	⑨
	④	Crib Work					④	④	④
5) Prevention of collapsing diffusion	⑬	Barrier with Gabion	⑬		⑬	⑬			
	⑭	Prevention Net	⑭		⑭	⑭	⑭		
	⑮	Barrier with Concrete Wall	⑮		⑮	⑮			
6) Avoidance of disaster	⑯	Relocation of Road							
	⑰	Bridge							
	⑱	Culvert							
	⑲	Rock Shed	⑲		⑲	⑲			
	⑳	Dam							
Alternative Countermeasure 1			⑦+⑨+⑬	⑥+⑨	⑦+⑬	⑦+⑬	⑥+⑨	⑥+⑨	⑥+⑨
Alternative Countermeasure 2			⑦+⑨+⑭	④+⑥+⑨+⑪	⑦+⑭	⑦+⑭	⑥+⑨+⑫	⑥+⑨+⑫	⑥+⑨+⑩
Alternative Countermeasure 3			⑦+⑨+⑮	⑩	⑦+⑮	⑦+⑮	⑥+⑨+⑪+④	⑥+⑨+⑪+④	⑥+⑨+⑪+④
Remarks			*⑧ is improper from the situation *Even ⑲ is unnecessary *⑨is crest ditch and roadside drain only		*⑧ is improper from the situation *Even ⑲ is unnecessary	*⑧ is improper from the situation *Even ⑲ is unnecessary	*⑭ is improper from necessary of prevention of weathering	* ⑨ is crest ditch and roadside drain only.	*⑨is crest ditch and roadside drain only. *⑫is improper from seepage water

Table 17.6.2 Countermeasure Alternatives for NIC.3 (Mountainside)

IDNo		N003B400	N003B370	N003B320	N003C230	N003E170	N003C150	N003C140
Distance		6.9	7.4	22.1	32.9	36.2	38.9	39.4
Purpose of Countermeasure		R.C Weathering	R.C Stability of Slope Weathering	R.C Stability of Slope Seepage water	R.C Stability of Slope Weathering Seepage water	R.C Stability of Slope	R.C Stability of Slope Seepage water	R.C Stability of Slope Seepage water
1) Increase of stability	① Widening Embankment ② Counterweight ③ Retaining Wall ④ Crib Work ⑤ Stone Masonry	④	④	① ③ ⑤	④	④	④	④
2) Removal of unstable material	⑥ Cutting ⑦ Removal ⑧ Splitting	⑥	⑥		⑥	⑥	⑥	⑥
3) Reduction of pore water pressure	⑨ Surface Drainage ⑩ Horizontal Drainage ⑪ Vegetation			⑨ ⑪	⑨ ⑩ ⑪	⑨	⑨ ⑩ ⑪	⑨ ⑩ ⑪
4) Prevention of erosion and weathering	⑪ Vegetation ⑫ Shotcrete ⑨ Surface Drainage ④ Crib Work	⑪ ⑫ ⑨ ④	⑪ ⑫ ⑨ ④	⑪	⑪ ⑨ ④	⑪		
5) Prevention of collapsing diffusion	⑬ Barrier with Gabion ⑭ Prevention Net ⑮ Barrier with Concrete Wall							
6) Avoidance of disaster	⑯ Relocation of Road ⑰ Bridge ⑱ Culvert ⑲ Rock Shed ⑳ Dam					⑯	⑲	⑲
Alternative Countermeasure 1		⑥+⑨	⑥+⑨	①+⑨+⑪	⑥+⑨	④+⑥	⑥+⑨	⑥+⑨+⑩
Alternative Countermeasure 2		⑥+⑨+⑫	⑥+⑨+⑫	①+③+⑨+⑪	④+⑥+⑨+⑪	④+⑥+⑨+⑪	④+⑥+⑨+⑪	④+⑥+⑨+⑩+⑪
Alternative Countermeasure 3		⑥+⑨+⑪+④	⑥+⑨+⑪+④	①+⑤+⑨+⑪	④+⑥+⑨+⑩+⑪	⑯	④+⑥+⑨+⑩+⑪	
Remarks					*⑫is improper from the situation		* ⑫is improper from the situation	* ⑫is improper from the situation

Table17.6.3 Countermeasure Alternatives for NIC.3 (Valleyside)

IDNo		N003B400	N003B370	N003B320	N003C230	N003E170	N003C150	N003C140
Distance		6.9	7.4	22.1	32.9	36.2	38.9	39.4
Purpose of Countermeasure					Stability of Slope Seepage water	Debris flow	Stability of Slope Seepage water	Stability of Slope Seepage water
1) Increase of stability	① Widening Embankment				①		①	①
	② Counterweight				②		②	②
	③ Retaining Wall				③		③	③
	④ Crib Work							
	⑤ Stone Masonry				⑤		⑤	⑤
2) Removal of unstable material	⑥ Cutting							
	⑦ Removal							
	⑧ Splitting							
3) Reduction of pore water pressure	⑨ Surface Drainage				⑨		⑨	⑨
	⑩ Horizontal Drainage							
4) Prevention of erosion and weathering	⑪ Vegetation				⑪		⑪	⑪
	⑫ Shotcrete							
	⑨ Surface Drainage							
	④ Crib Work							
5) Prevention of collapsing diffusion	⑬ Barrier with Gabion							
	⑭ Prevention Net							
	⑮ Barrier with Concrete Wall							
6) Avoidance of disaster	⑯ Relocation of Road					⑯		
	⑰ Bridge					⑰		
	⑱ Culvert					⑱		
	⑲ Rock Shed							
	⑳ Dam					⑳		
Alternative Countermeasure 1					①+⑨+⑪	⑯	①+⑨+⑪	①+⑨+⑪
Alternative Countermeasure 2					①+③+⑨+⑪	⑱+⑳	①+③+⑨+⑪	③+⑨+⑪
Alternative Countermeasure 3					①+⑤+⑨+⑪		①+⑤+⑨+⑪	⑤+⑨+⑪
Remarks					* ④ is unnecessary because embankment		*④ is unnecessary because embankment	* ④ is unnecessary because embankment

Table17.6.4 Countermeasure Alternatives for NIC.5

IDNo		N005A010						
Distance		24.6						
Purpose of Countermeasure		R.F Stability of Slope Seepage water						
1) Increase of stability	① Widening Embankment ② Counterweight ③ Retaining Wall ④ Crib Work ⑤ Stone Masonry	④						
2) Removal of unstable material	⑥ Cutting ⑦ Removal ⑧ Splitting	⑥						
3) Reduction of pore water pressure	⑨ Surface Drainage ⑩ Horizontal Drainage ⑪ Vegetation	⑨ ⑪						
4) Prevention of erosion and weathering	⑪ Vegetation ⑫ Shotcrete ⑨ Surface Drainage ④ Crib Work							
5) Prevention of collapsing diffusion	⑬ Barrier with Gabion ⑭ Prevention Net ⑮ Barrier with Concrete Wall							
6) Avoidance of disaster	⑯ Relocation of Road ⑰ Bridge ⑱ Culvert ⑲ Rock Shed ⑳ Dam							
Alternative Countermeasure 1		⑥+⑨						
Alternative Countermeasure 2		⑥+⑨+⑪						
Alternative Countermeasure 3		④+⑥+⑨+⑪						
Remarks								

Table17.6.5 Countermeasure Alternatives for NIC.26

IDNo		N026A060	N026B140	N026A150		N003C230	
Distance		24.7	34.0	34.2		37.0	
Purpose of Countermeasure		R.F Weathering	R.F Stability of Slope	Mountain side R.F Weathering	Valley side Stability of Slope	R.F	
1) Increase of stability	① Widening Embankment				①		
	② Counterweight				②		
	③ Retaining Wall				③		
	④ Crib Work		④	④			
	⑤ Stone Masonry				⑤		
2) Removal of unstable material	⑥ Cutting	⑥	⑥	⑥			
	⑦ Removal					⑦	
	⑧ Splitting					⑧	
3) Reduction of pore water pressure	⑨ Surface Drainage	⑨	⑨	⑨	⑨		
	⑩ Horizontal Drainage		⑩				
	⑪ Vegetation		⑪	⑪	⑪		
4) Prevention of erosion and weathering	⑪ Vegetation	⑪					
	⑫ Shotcrete	⑫					
	⑨ Surface Drainage	⑨					
	④ Crib Work	④					
5) Prevention of collapsing diffusion	⑬ Barrier with Gabion					⑬	
	⑭ Prevention Net					⑭	
	⑮ Barrier with Concrete Wall					⑮	
6) Avoidance of disaster	⑯ Relocation of Road		⑯	⑯			
	⑰ Bridge						
	⑱ Culvert						
	⑲ Rock Shed						
	⑳ Dam						
Alternative Countermeasure 1		⑥+⑨	⑥+⑨+⑩	⑥+⑨	⑨	⑦+⑬	
Alternative Countermeasure 2		⑥+⑨+⑫	④+⑥+⑨+⑩+⑪	④+⑥+⑨+⑪	①+③+⑨+⑪	⑦+⑭	
Alternative Countermeasure 3		⑥+⑨+⑪+④	⑯		①+⑨+⑪	⑦+⑮	
Remarks					*⑨is roadside drain only	* ⑧ is improper from the situation	