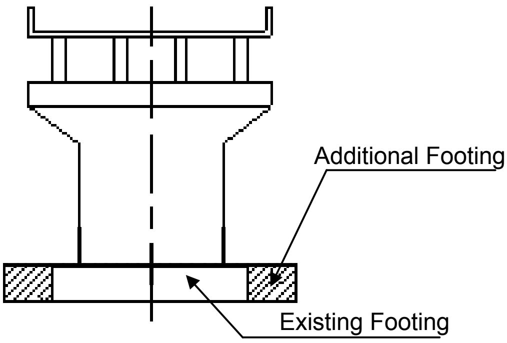
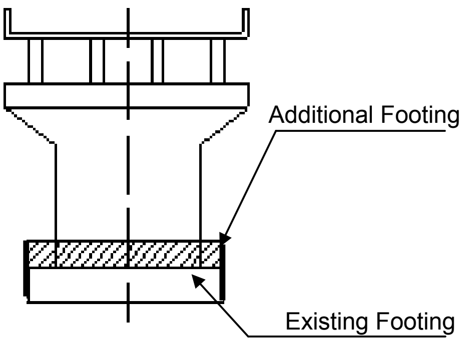
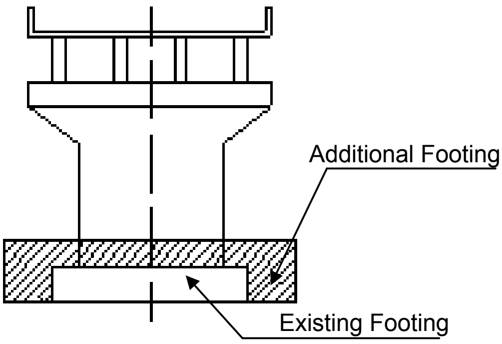
11.7 Foundation

The earthquake load and a scouring affect on the safety performance of the foundation. The earthquake loading will affect on the stabilization of foundation such as bearing capacity, turnover, and sliding directly. On the other hand, a scouring dose not affect the stabilization of foundation directly. However, when the scouring depth is deeper than the level of bottom of footing, the scouring affects on the stabilization of foundation, such as deteriorating of the bearing capacity or buckling of pile etc.

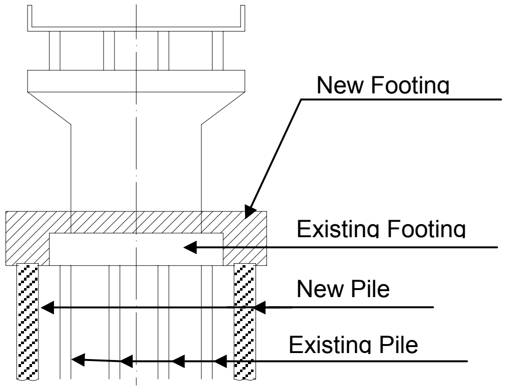
11.7.1 Method for Reinforcement for Foundation

Table 11.7.1 shows the principal examples of reinforcement method for foundation.

Table 11.7.1. Reinforce Methods for Foundation

Reinforce Method	Figures and Photos	Description of Method
Increase Dimension - Expand footing	 	By expanding footing size, the safety ratios of stabilization of foundation, such as bearing capacity, turnover (eccentricity) and sliding, are increased. By increasing thickness of footing, the load capacity of footing is increased.
- Increase thickness of footing	 	
- Expand footing and Increasing thickness of footing	 	

Increase Number of Pile
-Additional Pile Installation



By increasing pile number, the axial reaction of each pile is decreased.

By increasing thickness of footing, the load capacity of footing is increased against both push-in force and pull-out force of piles.

Under the superstructure, it is difficult to install new pile.

11.7.2 Selection of Reinforcement Method for Foundation

Among 10 bridges, 3 bridges, Rio Nuevo (No.16), Rio Sarapiqui (No.19), Rio Chirripo (No.26) are the pile foundation and other 7 bridges are spread foundation.

When the Reinforcement Method is selected for foundation, it is important to consider soil condition of bearing layer and construction condition. Generally Spread foundation has been located on substantial bearing layer that have enough bearing capacity against ground reaction and the pile foundation has been applied for soft soil layer.

In the case of 10 bridges, all spread foundations have been embedded in weather rock or stiff sand layer (SPT value more than 50) and bearing layers of all pile foundations are in more than 20m depth from the ground surface.

If spread foundation is reinforced by pile, its cost is higher than reinforcing methods shown in Table 11.7.1. These methods are the most reasonable method for reinforcement of spread foundation. However, where the existing spread foundation does not laid on the substantial layer, such as the stiff sand layer (SPT value is more than 30) with the thickness of more than 5m, hard clay layer (STP value is more than 20) or rock, it shall be reinforced by the piles.

In the case of pile foundation, it is clear that reinforcing method is only increasing number of piles. However, where the clearance under the superstructure is narrow or not enough space to set the equipments for piling, it is difficult to be reinforced by the additional piles. In this case, by changing support conditions of the superstructure, the seismic load for the foundation can be reduced.

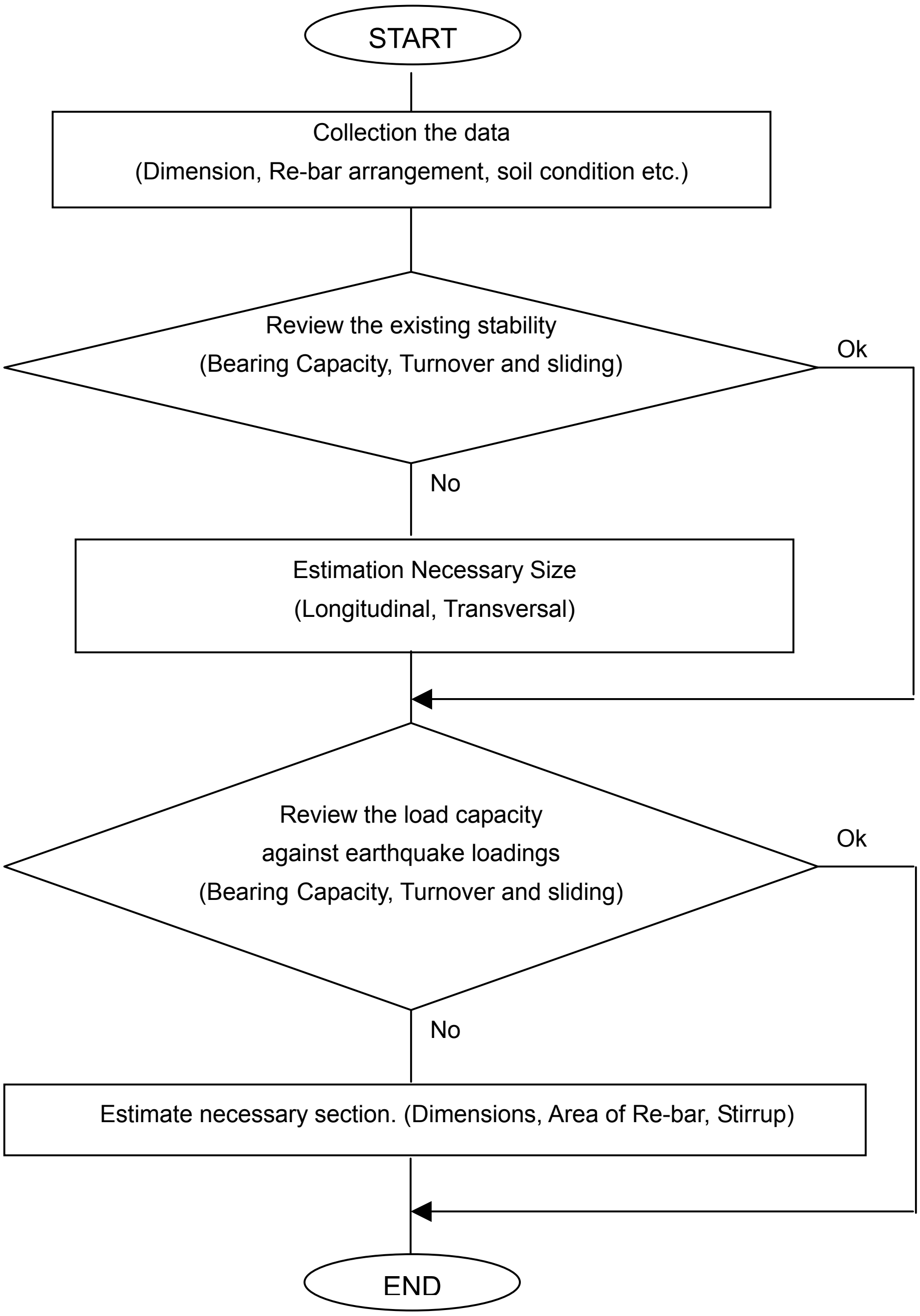


Figure 11.7.1. Design Process of Expanding of Footing

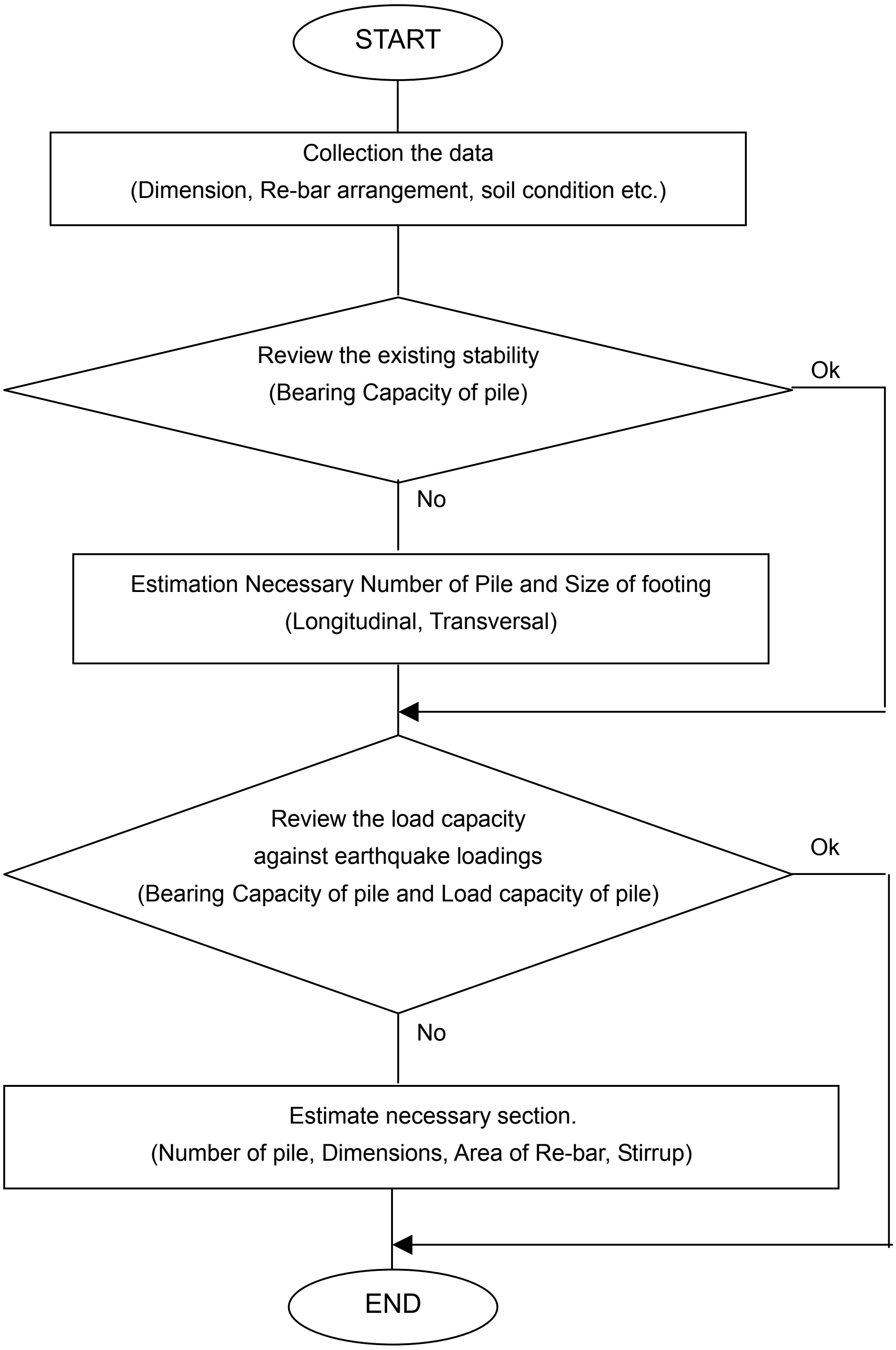


Figure 11.7.2. Design Process of Increased Number of Pile

11.7.3 Methodology of Design for Reinforcing of Foundation

The reinforcing of foundation shall be designed based on AASHOT or relevant standards and the Load Factor Design shall be applied to the design for reinforcing of footing. And the design shall be practiced following procedure.

1) Review of Stabilization of Foundation

Firstly the stabilization of foundation shall be reviewed when the reinforcing of foundation is practice

In the case of spread foundation it must be reviewed about three kind of stabilization factor, one is the bearing capacity of ground, second is condition of overturning of substructure that can be judged by excentric, determined the distance between center of footing and the point of resultant force working, and the safety factor of sliding.

For pile foundation it shall be judged by the pile reaction and load capacity of pile.

When the existing foundation is not satisfy above stabilization factor for spread foundation or pile reaction or load capacity of pile is less than the working force, the necessary size of footing or the number of piles and the layout of piles of the foundation must be estimated.

At this point the calculation shall be done inconsideration of the point shown below

- The original dead load is registered by the original foundation
- Additional dead load that is dead load of reinforcing section or earthquake loadings shall be registered by both original foundation and additional section

Therefore both original part and new part shall be calculated and checked whether it is satisfy the requirement or not. Especially original part has registered both cases so its reaction must be combined (Figure11.7.3).

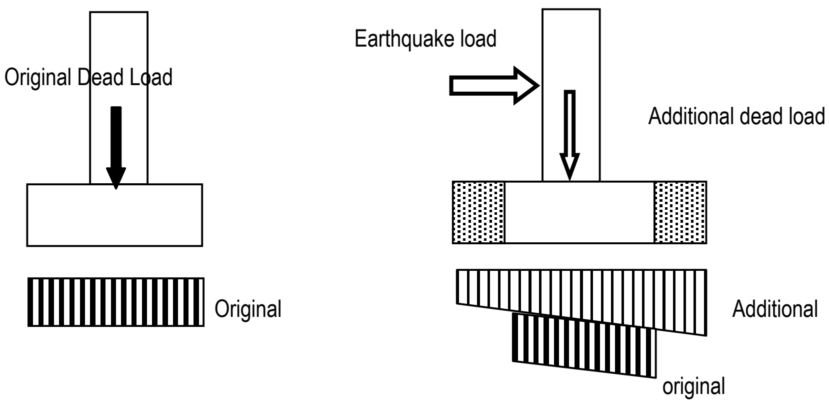


Figure 11.7.3. Judgment of Bearing Capacity

However when the value which the calculation result exceed the bearing capacity, safety factor or resister force is small and judged that it will not be affect the stabilization of foundation or it is within error of analysis, it may be less than 10%, it is not necessary to reinforce the foundation.

2) Review of Load Capacity

After the estimation of the necessary size of the footing or the number and the layout of piles, the load capacity of the footing shall be checked according to the load factor design method.

The foundation were reviewed the load capacity by comparing with the resisting/design force and working force about both bending moment and shear force. This time also the sequence of reinforcement shall be considered as same as the judgment of the stabilization of foundation.

The original dead load is carried by the original foundation and the additional dead load, which is the dead load of the reinforced section and earthquake loading shall be carried by both the original section and the increased section

The original section shall be checked for the cases of the original dead load, the additional dead load, and the earthquake loads. The load capacity of the footing structure shall be judged by the equations below.

$$\frac{Muo}{\phi Mo} + \frac{Mua + Mue}{\phi Mm} \leq 1.0$$

$$\frac{Vuo}{\phi Vo} + \frac{Vua + Vue}{\phi Vm} \leq 1.0$$

where:

Muo (Vuo)	:	Bending Moment (Shear force) caused by original dead load
Mua (Vua)	:	Bending Moment (Shear force) caused by additional dead load
Mue (Vue)	:	Bending Moment (Shear force) caused by earthquake loadings
ϕMo (ϕVo)	:	Design Moment (shear force) strength for original section
ϕMm(ϕVm)	:	Design Moment (shear force) strength for modified section (Original section + Reinforcing section)

11.7.4 Existing Condition and Condition after Reinforcement

1) Spread Foundation

The spread foundation is used for the 7 bridges excluding No.16 Nuevo BridgeNo.19 Sarapiqui Bridge and No.26 Chirripo Bridge. Table11.7.2 shows existing conditions of stability of the spread foundation, such as the ground reaction, the safety for turnover (eccentricity) and the sliding.

Except No.20 Sucio Bridge, some abutments and almost piers are unstable for the ground reaction and eccentricity, and they need the expanding footing widths.

All existing footings have been reviewed the load capacities for the dead load and seismic load. Table 11.7.3 shows the load capacities with the ratios of the resisting moment to the working moment (ϕ**Mo/Muo)** and the resisting shear force to the working shear **force(**ϕ **Vo/Vuo)**.

The 3 piers, P2 pier of Aranjues Bridge, P1 and P4 piers of in Puerto Nuevo Bridge, are required to increase the thickness of footings, and the other 3 piers, P1 pier of Abangares Bridge, P3 pier of Puerto Nuevo Bridge and P1 of Torres Bridge, are also required to increase the thickness of footing, because their original thickness are less than 1/5 (one fifth) of the expanded width of footing.

The required dimensions of footing for the earthquake load, and the conditions of load capacity after reinforcement, are shown in 11.7.2 and 11.7.3.

2) Pile Foundation

The pile foundations are used for the 3 bridges, No.16 Nuevo Bridge, No.19 Sarapiqui Bridge and No. 26 Chirripo Bridge. Table 11.7.4 shows the existing conditions of the axial reaction force of pile and the required number of piles. Table 11.7.5(a) shows the load capacity of existing footings. The existing load capacities of the piles for the push-in force and the pull-out force are shown in Table 11.7.5 (b). Table 11.7.5 (c) shows the conditions of load capacity after the reinforcement.

In Chirripo Bridge, both push-in and pull-out forces of piles are less than the allowable axial force. However, no reinforcement bars exist in the upper side of the footing, so that it can not resist the bending moment due to the pull-out force of piles. Therefore, The increasing of the thickness of footing with 50cm and the addition of reinforcement bars are required for the reinforcement of the footing.

In Sarapiqui Bridge, the axial push-in force of piles in P1 exceed the allowable bearing capacity of piles, so that the additional piles and the increasing of dimensions of footing are required. And as no reinforcement bars exist as same as Chirripo Bridge, the increasing of footing dimensions and the addition of reinforcement bars are required.

In Nuevo Bridge, the axial force of piles in both P1 and P2 foundations exceed the allowable bearing capacity of the pile. However, the existing pile of P1 is battered pile, and there is not enough space to drive piles. Therefore, P1 support condition was changed from the fixed support into the movable support condition, to reduce the seismic force acting to the P1 pier. And A1 abutment, which can be added the piles without the problems of clearance, has been changed to fixed support and reinforced by the addition of piles to carry the increased seismic force.

Table 11.7.2. Existing Condition of Spread Foundation and Required Size of Footing

Bridge Name		Member		Size		Bearing		Turnover		Sliding		Ratio			Required size
				B	D	Reaction	Capacity	exc	B/3	H	HR	Bearing	exc	HR/H	
2	Rio Aranjuez	A1	L	7.47	1.52	9.50	145.00	0.01	2.49	11.38	185.98	15.26	191.54	16.34	–
			T	3.66		9.80		0.01	1.22	166.00	185.98	14.80	93.85	1.12	–
		P1	L	3.05	1.52	89.80	116.00	2.20	1.02	134.00	428.87	1.29	0.46	3.20	**5.50**
			T	7.32		485.60		3.40	2.44	138.00	428.87	0.24	0.72	3.11	**9.00**
		P2	L	4.27	1.52	11.00	200.00	7.80	1.42	526.00	796.73	18.18	0.18	1.51	**11.50**
			T	7.32		210.50		3.20	2.44	140.00	796.73	0.95	0.76	5.69	**13.00**
		A2	L	3.05	1.40	8.20	116.00	0.02	1.02	3.90	149.64	14.15	68.00	38.37	–
			T	9.70		7.70		0.05	3.23	45.16	149.64	15.06	71.78	3.31	–
3	Rio Abangares	A1	L	4.57	0.91	31.30	146.00	3.93	1.52	112.90	205.68	4.66	0.39	1.82	**7.50**
			T	2.59		453.80		1.36	0.86	64.00	205.68	0.32	0.63	3.21	**4.50**
		P1	L	2.74	1.22	41.00	149.00	2.54	0.91	258.00	558.06	3.63	0.36	2.16	**6.50**
			T	12.50		48.60		1.78	4.17	173.00	558.06	3.07	2.35	3.23	**12.50**
		A2	L	5.49	1.22	96.70	154.00	3.42	1.83	146.00	239.38	1.59	0.54	1.64	**7.50**
			T	3.05		78.60		1.07	1.02	77.70	239.38	1.96	0.96	3.08	**5.00**
7	Rio Azufrado	P1	L	1.83	0.76	18.80	38.00	0.00	0.61	148.00	150.09	2.02	–	1.01	–
			T	8.23		32.60		1.01	2.74	55.00	150.09	1.17	2.72	2.73	–
		P2	L	1.83	0.76	18.80	63.00	0.00	0.61	148.00	150.09	3.35	–	1.01	–
			T	8.23		32.60		1.01	2.74	55.00	150.09	1.93	2.72	2.73	–
12	Rio Puerto Nuevo	A1	L	4.27	0.91	57.70	154.00	0.97	1.42	59.00	336.02	2.67	1.46	5.70	–
			T	3.05		44.20		0.44	1.02	35.50	336.02	3.48	2.31	9.47	–
		P1	L	4.57	1.22	53.50	182.00	0.89	1.52	98.60	327.13	3.40	1.71	3.32	**7.50**
			T	4.57		−148.70		2.79	1.52	31.44	327.13	−1.22	0.55	10.40	**7.50**
		P2	L	5.49	1.52	134.00	116.00	2.05	1.83	105.00	480.90	0.87	0.89	4.58	**6.00**
			T	5.49		63.28		1.20	1.83	63.00	480.90	1.83	1.53	7.63	**6.00**
		P3	L	5.03	1.22	50.90	190.00	0.89	1.68	34.00	391.86	3.73	1.88	11.53	**6.50**
			T	5.03		1353.10		2.45	1.68	95.00	391.86	0.14	0.68	4.12	**6.50**
		P4	L	4.57	1.22	322.70	182.00	1.98	1.52	78.00	405.67	0.56	0.77	5.20	**5.35**
			T	4.57		343.30		2.00	1.52	79.00	405.67	0.53	0.76	5.14	**5.50**
		A2	L	3.35	0.91	9161.90	143.00	1.67	1.12	64.00	201.70	0.02	0.67	3.15	**4.50**
			T	2.44		42.80		0.28	0.81	38.00	201.70	3.34	2.93	5.31	**2.50**
17	Rio Chirripo	P1	L	9.50	2.50	214.60	124.50	4.03	3.17	800.00	1460.66	0.58	0.79	1.83	**11.00**
			T	10.50		83.00		3.19	3.50	582.00	1460.66	1.50	1.10	2.51	**11.00**
		P2	L	9.50	2.50	214.60	124.50	4.03	3.17	800.00	1460.66	0.58	0.79	1.83	**11.00**
			T	10.50		83.00		3.19	3.50	582.00	1460.66	1.50	1.10	2.51	**11.00**
20	Rio Sucio	P1	L	12.50	2.50	37.90	116.00	0.02	4.17	5.00	3287.51	3.06	189.55	657.50	–
			T	12.50		55.20		2.89	4.17	507.00	3287.51	2.10	1.44	6.48	–
		P2	L	9.00	2.50	18.10	222.00	0.00	3.00	507.00	1099.96	12.27	15000.00	2.17	–
			T	12.50		19.40		0.45	4.17	215.00	1099.96	11.44	9.31	5.12	–
29	Rio Torres	A1	L	6.00	1.00	99.50	162.00	2.48	2.00	121.83	228.44	1.63	0.81	1.88	**6.50**
			T	3.50		65.20		1.29	1.17	66.75	228.44	2.48	0.91	3.42	**4.00**
		P1	L	7.50	1.10	15.00	175.00	0.22	2.50	15.66	430.74	11.67	11.63	27.51	**8.00**
			T	7.50		53.50		2.56	2.50	186.65	430.74	3.27	0.98	2.31	**8.00**
		P2	L	7.00	1.10	38.10	166.00	2.15	2.33	169.46	299.24	4.36	1.08	1.77	–
			T	7.00		11.20		0.02	2.33	169.93	299.24	14.82	129.44	1.76	–
		A2	L	3.50	0.90	62.40	135.00	2.31	1.17	61.50	114.38	2.16	0.51	1.86	**4.50**
			T	2.00		264.40		1.07	0.67	40.32	114.38	0.51	0.62	2.84	**3.00**

Table 11.7.3. The Load Carrying Capacity of the Footing at Existing Condition and after Reinforcement

Bridge Name		Member		Dead		EQ		Dead+EQ		Original				Required size		Additional						Original		Additional		Evaluation	
				Mud	Vud	Mue	Vue	Mu	Vu	φMo	φVo	φMo/Mu	φVo/Vu	B	D	MuA	VuA	MuA+Mue	VuA+Vue	φMA	φVA	Mud/φMo	Vuo/φVo	MuA/φMA	VuA/φVA	Mu/φM	Vu/φV
2	Rio Aranjuez	A1	L	0	23.949	1.262	0.7579	1.3	24.7	251.1	299.4	198.99	12.12	7.47	1.52	0.0	0.0	1.3	0.8	251.1	299.4	0.0	0.1	0.0	0.0	0.01	0.08
			T	0	48.879	0.8642	1.5677	0.9	50.4	431.3	611.0	499.02	12.11	3.66		0.0	0.0	0.9	1.6	431.3	611.0	0.0	0.1	0.0	0.0	0.00	0.08
		P1	L	38.563	141.47	72.532	216.81	111.1	358.3	243.5	598.8	2.19	1.67	5.50	1.52	1.5	2.5	74.0	219.3	299.4	736.2	0.2	0.2	0.2	0.3	0.41	0.53
			T	3.0945	18.423	3.5581	25.326	6.7	43.7	91.4	249.5	13.73	5.70	9.00		0.7	1.7	4.3	27.0	164.8	449.9	0.0	0.1	0.0	0.1	0.06	0.13
		P2	L	97.116	180.69	1623.7	471.16	1720.8	651.8	555.4	598.8	0.32	0.92	11.50	2.2	29.52	16.33	1653.2	487.5	2413.4	2171.3	0.2	0.3	0.7	0.2	0.86	0.53
			T	3.0945	17.675	3.6155	25.734	6.7	43.4	132.0	349.3	19.67	8.05	13.00		18.22	12.83	21.8	38.6	553.2	1740.4	0.0	0.1	0.0	0.0	0.06	0.07
		A2	L	0	47.414	0.72	1.7963	0.7	49.2	297.1	726.4	412.64	14.76	3.05	1.4	0.0	0.0	0.7	1.8	297.1	726.4	0.0	0.1	0.0	0.0	0.00	0.07
			T	0	0.9174	0.0097	0.0671	0.0	0.9	92.8	228.4	9592.00	253.77	9.70		0.0	0.0	0.0	0.1	92.8	228.4	0.0	0.0	0.0	0.0	0.00	0.00
3	Rio Abangares	A1	L	3.23	19.84	10.47	44.36	13.7	64.2	52.1	121.5	3.81	1.89	7.50	0.91	1.5	2.1	12.0	46.4	90.6	211.1	0.1	0.2	0.1	0.2	0.19	0.38
			T	14.61	49.41	22.18	59.46	36.8	108.9	81.2	214.4	2.21	1.97	4.50		0.6	1.4	22.8	60.8	133.3	351.8	0.2	0.2	0.2	0.2	0.35	0.40
		P1	L	34.473	159.23	97.253	405.78	131.7	565.0	335.4	805.9	2.55	1.43	6.50	1.5	4.18	4.45	101.4	410.2	335.4	1813.9	0.1	0.2	0.3	0.2	0.41	0.42
			T	-	-	-	-	-	-	-	-	-	-	12.50		-	-	-	-	-	-	-	-	-	-	-	-
		A2	L	30.61	57.20	55.54	86.61	86.2	143.8	279.2	196.6	3.24	1.37	7.50	1.22	0.8	1.6	56.4	88.2	457.7	322.3	0.1	0.3	0.1	0.3	0.23	0.56
			T	32.46	83.10	26.17	57.95	58.6	141.1	259.5	353.9	4.43	2.51	5.00		0.8	1.6	26.9	59.5	354.5	483.5	0.1	0.2	0.1	0.1	0.20	0.36
7	Rio Azufrado	P1	L	19.19	77.35	0.00	0.00	19.2	77.4	223.7	313.8	11.66	4.06	1.83	0.76	0.0	0.0	0.0	0.0	223.7	313.8	0.1	0.2	0.0	0.0	0.09	0.25
			T	5.37	19.14	1.44	4.88	6.8	24.0	23.6	69.8	3.46	2.91	8.23		0.0	0.0	1.4	4.9	23.6	69.8	0.2	0.3	0.1	0.1	0.29	0.34
		P2	L	19.19	77.35	0.00	0.00	19.2	77.4	223.7	313.8	11.66	4.06	1.83	0.76	0.0	0.0	0.0	0.0	223.7	313.8	0.1	0.2	0.0	0.0	0.09	0.25
			T	5.37	19.14	1.44	4.88	6.8	24.0	23.6	69.8	3.46	2.91	8.23		0.0	0.0	1.4	4.9	23.6	69.8	0.2	0.3	0.1	0.1	0.29	0.34
12	Rio Puerto Nuevo	A1	L	36.691	75.944	2.794	4.418	33.9	71.5	173.8	143.1	5.13	2.00	4.27	0.914	0.00	0.00	2.8	4.4	173.8	143.1	0.2	0.5	0.0	0.0	0.23	0.56
			T	23.276	68.433	12.635	24.127	35.9	92.6	81.2	200.3	2.26	2.16	3.05		0.00	0.00	12.6	24.1	81.2	200.3	0.3	0.3	0.2	0.1	0.44	0.46
		P1	L	91.381	141.6	32.718	49.108	124.1	190.7	281.4	294.6	2.27	1.54	7.50	1.5	2.70	3.68	35.4	52.8	424.0	899.5	0.3	0.5	0.1	0.1	0.41	0.54
			T	91.381	141.6	123.15	181.08	214.5	322.7	281.4	294.6	1.31	0.91	7.50		2.70	3.68	125.8	184.8	424.0	899.5	0.3	0.5	0.3	0.2	0.62	0.69
		P2	L	171.11	210.68	140.35	151.57	311.5	362.2	519.5	450.3	1.67	1.24	6.00	1.52	0.02	0.15	140.4	151.7	478.0	837.8	0.3	0.5	0.3	0.2	0.62	0.65
			T	171.11	210.68	83.309	89.973	254.4	300.7	519.5	450.3	2.04	1.50	6.00		0.02	0.15	83.3	90.1	478.0	837.8	0.3	0.5	0.2	0.1	0.50	0.58
		P3	L	121.6	168.09	44.32	55.783	165.9	223.9	460.6	324.2	2.78	1.45	6.50	1.5	0.50	1.36	44.8	57.1	603.1	848.4	0.3	0.5	0.1	0.1	0.34	0.59
			T	121.6	168.09	121.72	153.2	243.3	321.3	460.6	324.2	1.89	1.01	6.50		0.50	1.36	122.2	154.6	603.1	848.4	0.3	0.5	0.2	0.2	0.47	0.70
		P4	L	106.17	173.14	94.919	142.47	201.1	315.6	281.4	294.6	1.40	0.93	5.35	1.5	0.12	0.59	95.0	143.1	352.7	738.2	0.4	0.6	0.3	0.2	0.65	0.78
			T	106.17	173.14	95.782	143.8	201.9	316.9	281.4	294.6	1.39	0.93	5.50		0.16	0.71	95.9	144.5	352.7	738.2	0.4	0.6	0.3	0.2	0.65	0.78
		A2	L	16.03	44.75	21.26	48.12	37.3	92.9	91.9	114.5	2.46	1.23	4.50	0.91	0.10	0.34	21.4	48.5	94.2	117.3	0.2	0.4	0.2	0.4	0.40	0.80
			T	29.46	93.35	9.17	25.88	20.3	67.5	46.5	157.3	2.29	2.33	2.50		0.00	0.02	9.2	25.9	62.4	211.1	0.6	0.6	0.1	0.1	0.78	0.72
17	Rio Chirripo	P1	L	952.5	652.9	1126.2	596.3	2078.7	1249.3	3693.1	1451.6	1.78	1.16	11.00	2.5	0.30	0.79	1126.5	597.1	3868.9	1520.7	0.3	0.4	0.3	0.4	0.55	0.84
			T	430.38	455.91	411.59	321.9	842.0	777.8	2681.0	1313.4	3.18	1.69	11.00		0.03	0.26	411.6	322.2	3104.3	1520.7	0.2	0.3	0.1	0.2	0.29	0.56
		P2	L	952.55	652.93	1126.2	596.35	2078.7	1249.3	3693.1	1451.6	1.78	1.16	11.00	2.5	0.30	0.79	1126.5	597.1	3868.9	1520.7	0.3	0.4	0.3	0.4	0.55	0.84
			T	430.38	455.91	411.59	321.9	842.0	777.8	2681.0	1313.4	3.18	1.69	11.00		0.03	0.26	411.6	322.2	3104.3	1520.7	0.2	0.3	0.1	0.2	0.29	0.56
20	Rio Sucio	P1	L	1603.7	1156.2	9.0639	4.9583	1612.8	1161.2	6312.6	1885.5	3.91	1.62	12.50	2.5	0.00	0.00	9.1	5.0	6312.6	1885.5	0.3	0.6	0.0	0.0	0.26	0.62
			T	1603.7	1156.2	1169.6	639.81	2773.3	1796.1	6403.8	1885.5	2.31	1.05	12.50		0.00	0.00	1169.6	639.8	6403.8	1885.5	0.3	0.6	0.2	0.3	0.43	0.95
		P2	L	603.35	490.54	0.1254	0.0664	603.5	490.6	4427.5	1885.5	7.34	3.84	9.00	2.5	0.00	0.00	0.1	0.1	4427.5	1885.5	0.1	0.3	0.0	0.0	0.14	0.26
			T	411.55	347.01	62.692	34.295	474.2	381.3	3894.7	1357.6	8.21	3.56	12.50		0.00	0.00	62.7	34.3	3894.7	1357.6	0.1	0.3	0.0	0.0	0.12	0.28
29	Rio Torres	A1	L	96.35	106.89	51.906	49.496	44.4	57.4	227.5	181.5	5.12	3.16	6.50	1.3	0.04	0.30	51.9	49.8	259.9	269.6	0.4	0.6	0.2	0.2	0.62	0.77
			T	22.911	57.298	38.461	56.979	61.4	114.3	102.7	311.1	1.67	2.72	4.00		0.04	0.30	38.5	57.3	111.3	438.1	0.2	0.2	0.3	0.1	0.57	0.31
		P1	L	210	164.53	18.069	10.951	228.1	175.5	725.1	432.0	3.18	2.46	8.00	1.6	0.05	0.38	18.1	11.3	773.5	670.3	0.3	0.4	0.0	0.0	0.31	0.40
			T	210	164.53	215.42	130.56	425.4	295.1	725.1	432.0	1.70	1.46	8.00		0.05	0.38	215.5	130.9	773.5	670.3	0.3	0.4	0.3	0.2	0.57	0.58
		P2	L	130.18	116.1	132.37	88.505	262.6	204.6	495.5	403.2	1.89	1.97	7.00	1.1	0.00	0.00	132.4	88.5	495.5	403.2	0.3	0.3	0.3	0.2	0.53	0.51
			T	130.18	116.1	1.1392	0.7617	131.3	116.9	495.5	403.2	3.77	3.45	7.00		0.00	0.00	1.1	0.8	495.5	403.2	0.3	0.3	0.0	0.0	0.27	0.29
		A2	L	17.83	41.837	1.0785	2.2077	16.8	39.6	56.7	92.2	3.38	2.33	4.50	0.9	0.13	0.52	1.2	2.7	85.0	138.2	0.3	0.5	0.0	0.0	0.33	0.47
			T	4.734	25.748	9.3297	32.093	14.1	57.8	51.3	161.3	3.65	2.79	3.00		0.13	0.52	9.5	32.6	66.0	207.4	0.1	0.2	0.1	0.2	0.24	0.32

Table 11.7.4. Axial Reaction Force of Piles and Required Number of Piles

(a) Axial Force of Piles of Original Structure

Bridge Name				Original Size			Dead	EQ		qo+qe					Evaluation		
				B	t	Pile	qo	qemax	qe min	max	min	Qa	Qa(EQ)	Ta(EQ)	Dead	EQ(Max)	EQ(Min)
26	Chirripo	P1	L	2.20	1.80	2	32.8	80.7	−80.7	113.5	−47.9	106.47	229.7	−76.4	3.25	2.02	1.59
			T	7.30		8	32.8	100.1	−100.1	132.9	−67.3	106.47	229.7	−76.4	3.25	1.73	1.14
		P2	L	2.80	2.00	25	13.1	49.3	−49.3	62.4	−36.2	106.47	229.7	−76.4	8.13	3.68	2.11
			T	7.70			13.1	55	−55	68.1	−41.9	106.47	229.7	−76.4	8.13	3.37	1.82
		P3	L	5.20	2.00	35	33.6	96.2	−96.2	129.8	−62.6	106.47	229.7	−76.4	3.17	1.77	1.22
			T	8.20			33.6	46	−46	79.6	−12.4	106.47	229.7	−76.4	3.17	2.89	6.16
		P4	L	5.20	2.00	35	38.9	95.4	−95.4	134.3	−56.5	106.47	229.7	−76.4	2.74	1.71	1.35
			T	8.20			38.9	49.3	−49.3	88.2	−10.4	106.47	229.7	−76.4	2.74	2.60	7.35
19	Sarapiqui	P1	L	2.20	2.00	2	39	80.7	−80.7	119.7	−41.7	63.63	92.93	−30.77	1.63	0.78	0.74
			T	6.90		13	39	100.1	−100.1	139.1	−61.1	63.63	92.93	−30.77	1.63	0.67	0.50
		P2	L	3.05	2.50	4	13.1	26.8	−26.8	39.9	−13.7	63.63	99.25	−33.08	4.86	2.49	2.41
			T	9.80		13	13.1	24.7	−24.7	37.8	−11.6	63.63	99.25	−33.08	4.86	2.63	2.85
16	Nuevo	P1	L	2.74	0.914	4	14.3	197	−197	211.3	−182.7	44.865	66.4	−22.1	3.14	0.31	0.12
			T	7.77		6	14.3	22.7	−22.7	37	−8.4	44.865	66.4	−22.1	3.14	1.79	2.63
		P2	L	3.66	0.914	3	18.91	0	0	18.91	18.91	40.05	66.4	−22.1	2.12	3.51	−
			T	7.77		6	18.91	30.23	−30.23	49.14	−11.32	40.05	66.4	−22.1	2.12	1.35	1.95

(b) Axial Force of Piles of Reinforced Structure

Bridge Name				Modified Size			Original Pile					Additional Pile		Allowable Capacity	
				No.of pile	Size of footing		Dead	EQ		qo+qe		EQ			
					B	t	qo	qemax	qe min	max	min	qemax	qe min	Qa(EQ)	Ta(EQ)
19	Sarapiqui	P1	L	4	5.4	3.00	39.0	10.0	−22.1	49.0	29.0	26.5	−26.5	92.9	−30.8
			T	13	8.9		39.0	50.0	−22.1	89.0	−11.0	−	−	92.9	−30.8
16	Nuevo	P1	L	2.74	0.914	4	14.3	10.4	−22.1	24.7	3.9	−	−	66.4	−22.1
			T	7.77		6	14.3	22.7	−22.1	37.0	−8.4	−	−	66.4	−22.1
		P2	L	3.66	0.914	3	18.9	17.3	−22.1	36.2	1.6	−	−	66.4	−22.1
			T	7.77		6	18.9	30.2	−22.1	49.1	−11.3	−	−	66.4	−22.1

Note ; The support condition in Rio Nuevo was changed, both pier are movable support.

Table 11.7.5. Condition of Load Carrying Capacity of Footing

(a) Load Carrying Capacity of original Footing

Bridge Name				Original Size			Muo	Vuo	Me	Ve	Muo+Me	Vuo+Ve	φ Mo	φ Vo	φ Mo /(Muo+Me)	φ Vo /(Vuo+Ve)
				B	t	Pile	tm	ton	tm	ton	tm	ton	tm	ton		
26	Chirripo	P1	L	8.00	1.80	2	0	0	0	0	0.0	0.0	457.8	597.1	−	−
			T	10.00		8	91.86	131.22	46.54	60.05	138.4	191.3	570.1	180.0	4.1	0.9
		P2	L	8.00	2.00	25	27.25	272.52	11.49	114.94	38.7	387.5	523.2	718.5	13.5	1.9
			T	10.00			194.66	194.66	83.31	79.72	278.0	274.4	840.4	261.3	3.0	1.0
		P3	L	11.00	2.00	35	107.51	503.96	350.47	371.08	458.0	875.0	1435.5	765.2	3.1	0.9
			T	11.00			255.34	235.18	106.81	92.88	362.2	328.1	1197.3	485.2	3.3	1.5
		P4	L	11.00	2.00	35	430.82	525.39	347.40	367.83	778.2	893.2	1435.5	765.2	1.8	0.9
			T	11.00			266.20	245.18	113.49	98.68	379.7	343.9	1197.3	485.2	3.2	1.4
19	Sarapiqui	P1	L	8.00	2.00	2	50.69	350.94	34.99	242.22	85.7	593.2	193.3	643.9	2.3	1.1
			T	8.00		13	175.47	155.97	137.62	116.77	313.1	272.7	472.2	205.3	1.5	0.8
		P2	L	5.00	2.50	4	107.31	170.34	73.25	116.27	180.6	286.6	265.8	914.5	1.5	3.2
			T	11.00		13	393.09	209.65	206.23	98.99	599.3	308.6	976.6	284.6	1.6	0.9
16	Nuevo	P1	L	2.74	0.914	4	78.40	85.88	360.94	395.33	439.3	481.2	158.0	128.7	0.4	0.3
			T	7.77		6	21.70	57.25	11.459	30.234	33.2	87.5	75.3	171.6	2.3	2.0
		P2	L	3.66	0.914	3	51.39	113.4407	15.688	11.459	67.1	124.9	57.9	128.7	0.9	1.0
			T	7.77		6	21.50	56.72	34.631	30.234	56.1	87.0	57.9	128.7	1.0	1.5

(b) Load Capacity of Footing against Push-in Force after Reinforcement

Bridge Name				Axial Push-in Force												
				No.of pile	Size of footing B	Size of footing t	Me (tm)	Ve (ton)	ϕMm (tm)	ϕVm (ton)	(1) Muo/ϕMo	(2) Vuo/ϕVo	(3) Me/ϕMm	(4) ve/ϕVm	Evaluation (1)+(3)	Evaluation (2)+(4)
26	Chirripo	P1	L	2	2.2	2.30	0.0	0.0	621.6	1028.6	0.000	0.000	0.000	0.000	0.000	0.000
			T	8	7.3		46.5	60.1	791.4	464.5	0.161	0.729	0.059	0.129	0.220	0.858
		P2	L	25	2.8	2.50	11.5	114.9	686.9	1184.6	0.052	0.379	0.017	0.097	0.069	0.476
			T		7.7		83.3	79.7	1123.2	586.2	0.232	0.745	0.074	0.136	0.306	0.881
		P3	L	35	5.2	2.50	350.5	371.1	1894.2	1245.6	0.075	0.659	0.185	0.298	0.260	0.957
			T		8.2		106.8	92.9	1587.2	879.3	0.213	0.485	0.067	0.106	0.281	0.590
		P4	L	35	5.2	2.50	347.4	367.8	1894.2	1245.6	0.300	0.687	0.183	0.295	0.484	0.982
			T		8.2		113.5	98.7	1587.2	879.3	0.222	0.505	0.072	0.112	0.294	0.618
19	Sarapiqui	P1	L	4	5.4	3.00	90.6	109.5	233.9	1343.2	0.262	0.545	0.387	0.082	0.650	0.627
			T	13	8.9		137.6	116.8	233.7	815.0	0.372	0.760	0.589	0.143	0.960	0.903
		P2	L	4	5.05	2.50	73.2	116.3	348.2	1441.0	0.404	0.186	0.210	0.081	0.614	0.267
			T	13	11.8		206.2	99.0	1306.4	616.7	0.402	0.737	0.158	0.161	0.560	0.897

(c) Reinforcement of Footing against Pull-Out Force

Bridge Name				Axial Push-in Force							
				No.of pile	Size of footing B	Size of footing t	qo+qe max	qo+qe min	M	Required Re-bar size	Required Re-bar space(cm)
26	Chirripo	P1	L	2	2.2	2.3	113.5	-47.9	-321.46	# 5	30
			T	8	7.3		132.9	-67.3	-532.8	# 8	25
		P2	L	25	2.8	2.5	62.4	-36.2	-428.25	# 5	30
			T		7.7		68.1	-41.9	-710	# 9	30
		P3	L	35	5.2	2.5	129.8	-62.6	-1998	# 10	25
			T		8.2		79.6	-12.4	-1241.3	# 10	30
		P4	L	35	5.2	2.5	134.3	-56.5	-1971	# 10	25
			T		8.2		88.2	-10.4	-1250.6	# 10	30
19	Sarapiqui	P1	L	4	5.4	3	49	29	-571.39	# 5	30
			T	13	8.9		89	-11	-825.7	# 9	25
		P2	L	4	5.05	2.5	39.9	-13.7	-522.8	# 5	25
			T	13	11.8		37.8	-11.6	-1193.2	# 10	20

11.7.5 Scouring

1) Method of Protection for Scouring

There are three types of phenomenon regarding scouring as mentioned below

(a) Long-term degradation of the riverbed
(b) General scour at the bridge
(c) Local scour at the piers or abutments

For the phenomenon (b), “General scour at the bridge” and (c) “Local scour at the piers or abutments”, it is most important to carry out a frequent inspection and the maintenance works with an appropriate period. Moreover, it is also an important action to stop the gathering sand from the riverbed at upstream side of the bridge.

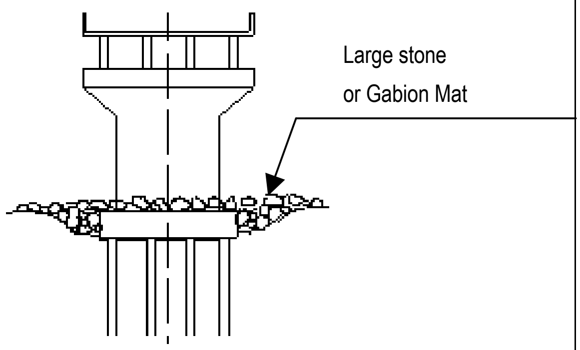
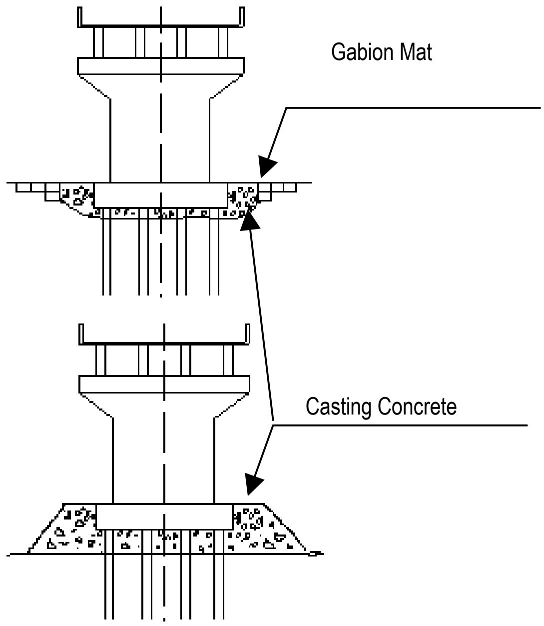
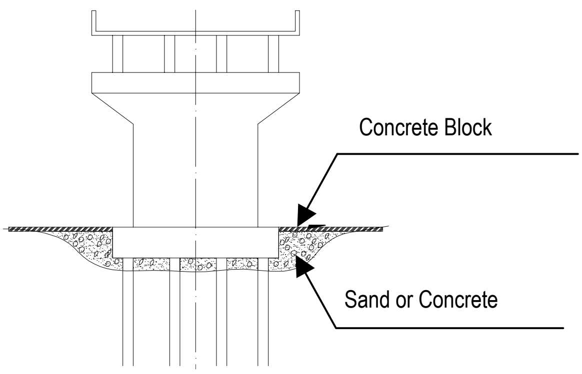
The methods of protection for scouring are shown in Table 11.7.6.

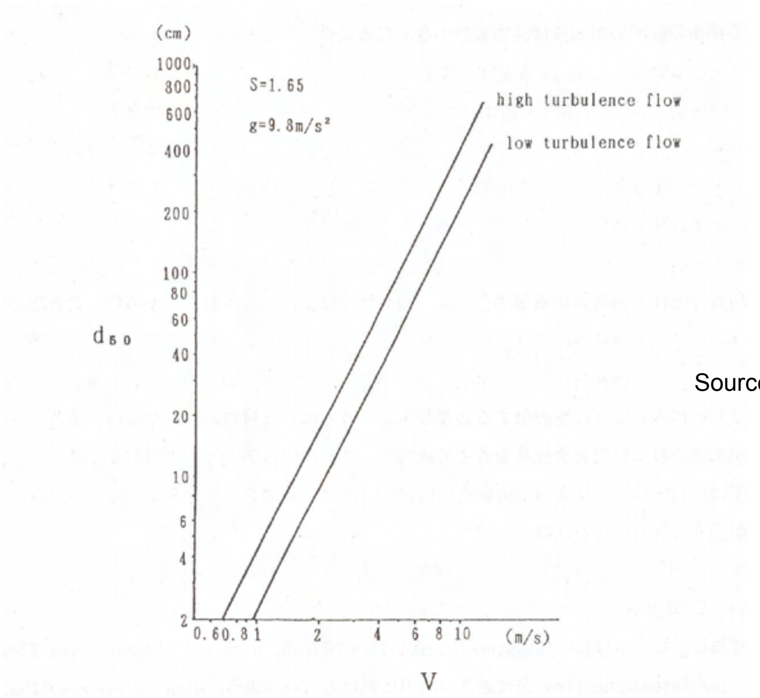
Where the protection for scouring are carried out on site, it is important that the levels of the top of filling or the concrete block shall be same as the original riverbed level before scoured except the case of “Long-term degradation of the riverbed”. Because, if the level of filling or the concrete block is higher than original riverbed, it causes other scouring.

Rio Nuevo (No.16)		
Rio Torres (No.29)		

Figure11.7.4. Scouring of Riverbed around Pier

Table 11.7.6. Method for Riverbed Protection

Material	Illustration	Remarks
Big Stone and Gabion		- This measure is applied to the case that the velocity is slow or the soil in riverbed is clay or loose sand since its shape can be changed flexibly according to the settlement of riverbed. - This method is also applied to the temporally measure when the velocity is fast or there are many boulders. - This method is economical and facility for construction is simple and easy. - It is required the continuous maintenance such as frequency inspection and maintenance work.
Protection by casting Concrete		- This measure is applied to the case that the large scouring occurred. - Gabion mat shall be installed to prevent scour in the edge of casting concrete. - If riverbed will be settled by the weight of casting concrete, the concrete may have cracks. - To cast concrete in site the cofferdam shall be required. May be this method shall be carried out on dry season. - Since concrete poured the scouring hole direct, it was required to follow the environmental regulations.
Protection by precast concrete block		- This measure is applied to the any case, however the velocity shall determine the size of block. One of the proposition of the relationship between flow velocity and weight or size of stone is shown in Figure 11.7.5 and Table11.7.7 - The scouring hole is filled by sand or Concrete and then concrete blocks are laid riverbed. - This method is most effective method against scouring for the sandy or gravel riverbed.



Source: " Technical Note of Public Works Research Institute No.3225 "Study on the influence of the pier upon the river from view of flood control" November 1998

Figure 11.7.5. Relation between Size of Stone for Protection and Velocity

Table 11.7.7. Relation between Weight of Concrete Block and Velocity

Shape of Concrete Block	Weight of Block (ton)	Maximum Velocity to move concrete block (m/sec)
Flat Type	1.02	3.31
	2.012	3.7
	3.036	3.97
	4.014	4.15
	5.025	4.31

Source: " Technical Note of Public Works Research Institute No.3225 "Study on the influence of the pier upon the river from view of flood control" November 1998

2) Existing Condition and Countermeasure

From the result of inspection in site, large scale scouring were observed at no.16 Nuevo Bridge and No.29 Torres Bridge as shown in Figure 11.7.4. The results of inspection for scouring and the countermeasures are summarized in Table 11.7.8.

The conditions of scouring in Nuevo Bridge is most serious case in 10 bridges. The piles exposed from the riverbed with a height of around 2m. This exposing of piles are caused by the Long-term degradation of the riverbed.

Table 11.7.8. Condition of Scouring and Countermeasures

Bridge No.	Condition of scouring		Damage of surface of Pier by River flow or Rolling Stone	Countermeasures
	Pier	Abutment		
Rio Aranjues (No.2)	Small (b)	Not Observed	Small	Intensification of inspection
Rio Abangares (No.3)	Not Observed	Not Observed	Not Observed	Periodic inspection
Rio Azufrado (No.7)	Not Observed	Not Observed	Not Observed	Periodic inspection
Rio Puerto Nuevo (No.12)	Not Observed	Collapse	Not Observed	Protected by Concrete wall
Rio Nuevo (No.16)	Big (a)	Not Observed	Not Observed	Fill concrete between pile and install mat gabion and concrete block to protect the riverbed around pier.
Rio Chirripo (No.17)	Small (c)	Not Observed	Big	- Protected by concrete - Intensification of inspection
Rio Sarapiqui (No.19)	Small (a),(c)	Not Observed	Not Observed	Intensification of inspection
Rio Sucio (No.20)	Small (a)	Not Observed	Big	- Protected by concrete - Intensification of inspection
Rio Chirripo (No.26)	Small (b) (c)	Not Observed	Not Observed	Intensification of inspection
Rio Torres (No.29)	Big (a)	Not Observed	Not Observed	Protected by revetment or gabion Mat

Note: ( ) shows the cause of scouring shows below
(a) Long-term degradation of the riverbed
(b) General scour at the bridge
(c) Local scour at the piers or abutments

11.8 Summary of Design for Rehabilitation, Reinforcement and Improvement of 10 Selected Bridges

The rehabilitation, reinforcement and improvement methods for selected 10 bridges are summarized in Table 11.8.1. and 11.8.2

Table 11.8.1 Summary of Rehabilitation, Reinforcement and Improvement Method for Superstructures of 10 Selected Bridges

(Methods marked with ○ will be executed)

Member	Repair and Reinforcement Methods	R1			R2			R4		R32		R216
		2	3	7	12		16	17	19	20	26	29
		ST	ST	RI	SI	RI	RI	PB	SI	PB	SI	PI
Deck slab	Concrete Thickness Increasing on Upper side			○			○					
	FRP Bonding on				○	○			○		○	
	Replacement (PC Panel)	○	○									
Floor System And Main Girder of Steel Bridge	Slab Replacement	○	○	N/A		N/A	N/A	N/A		N/A		N/A
	Member Section Increasing		○	N/A		N/A	N/A	N/A	○	N/A		N/A
	Member Addition	○		N/A		N/A	N/A	N/A		N/A		N/A
	Steel Plate Replacement			N/A		N/A	N/A	N/A	○	N/A		N/A
	Out-Cable Addition			N/A	○	N/A	N/A	N/A	○	N/A		N/A
Main Girder of RC, PC bridges	Out-Cable Addition	N/A	N/A	○	N/A				N/A		N/A	
	FRP Bonding	N/A	N/A		N/A		○		N/A		N/A	○
	Steel Plate Bonding	N/A	N/A	○	N/A	○			N/A		N/A	
Bridge Accessory	Replacement of Expansion Joint	○	○	○	○	○	○	○	○	○	○	○
	Bearing Support Repairing						○				○	
	Railing Replacement	○	○									
Paving	Asphalt Paving	○	○	○	○	○	○	○	○	○	○	○
	Waterproofing	○	○	○	○	○	○	○	○	○	○	○

Table 11.8.2 Summary of Rehabilitation, Reinforcement and Improvement Method for Substructures of 10 Selected Bridges

(Methods marked with ○ will be executed)

Member	Repair and Reinforcement Methods	R1			R2		R4		R32		R216
		2	3	7	12	16	17	19	20	26	29
		ST	ST	RI	SI,RI	RI	PB	SI	PB	SI	PI
Substructure	Beam Section Increasing				○			○		○	○
	Concrete Jacketing	○	○	○		○					○
	Pier Protection						○		○		
Foundation	Footing Widening	○	○	○	○	○	○	○		○	○
	Pile Addition	N/A	N/A	N/A	N/A	○	N/A	○	N/A		N/A
Prevention System for Bridge Falling Down	Securing of Bridge Seat Length, Limitation System for Girder Movement	○	○		○	○		○		○	○
	Aseismatic Girder Connection		○		○			○		○	
Protection Work	Slope Protection (Riprap)	○			○	○					
	Riverbed Protection (Gabion Mat)	○	○		○	○				○	○

CHAPTER 12 PRELIMINARY CONSTRUCTION PLANNING AND COST

12.1 Preliminary Construction Planning

12.1.1 General

Preliminary construction planning of rehabilitation project for 10 bridges (hereafter referred as “the Project”) is on the basis of analysis and design result described in Chapter 11.

Note progress of the work for the Project without entire traffic closure is crucial considering social and economic aspects because those bridges are located at highly important trunk roads in Costa Rica.

12.1.2 Contents of Rehabilitation Works for Selected 10 Bridges

Rehabilitation work items and their quantities as the design results are followings.

Table 12.1.1. Bridge No.2 Rio Aranjuez (R.1)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	Slab replacement (precast slab)	m^2	720.00
	Floor system	Stringer addition & re-arrangement	ton	55.07
	Main girder	Member addition	ton	18.03
	Prevention system for unseating	Bridge seat widening (A1)	m^3	4.06
		Bridge seat widening (P1)	m^3	8.54
		Bridge seat widening (P2)	m^3	8.54
		Bridge seat widening (A2)	m^3	2.99
	Accessory	New installation of expansion joint	m	18.30
		Flexible railing installation	m	200.24
		Asphalt paving & waterproofing	m^2	649.65
Substructure	Pier	Concrete jacketing (P2)	m^3	50.80
	Foundation	Footing widening (P1)	m^3	41.30
		Footing widening (P2)	m^3	281.39
		Install gabion box (A1)	m^2	180.00
		Install gabion box (P1)	m^2	396.00
		Install gabion box (P2)	m^2	396.00
		Wet masonry (A1)	m^3	150.00

Table 12.1.2. Bridge No. 3 Rio Abangares (R.1)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	Slab replacement (precast slab)	m^2	703.00
	Floor system	Stringer addition & re-arrangement (129ft section)	ton	35.28
		Stringer addition & re-arrangement (200ft section)	ton	57.44
	Main girder	Diaphragm re-arrangement	ton	5.17
		Cover plate fixing	ton	0.76
	Prevention system for unseating	Bridge seat widening (A1)	m^3	1.41
		Bridge seat widening (P1)	m^3	6.74
		Bridge seat widening (A2)	m^3	2.47
		Connection system (chain type)	no	24.00
	Accessory	New installation of expansion joint	m	26.45
		Flexible railing installation	m	202.68
		Asphalt paving & waterproofing	m^2	741.30
Substructure	Pier	Concrete jacketing (P1)	m^3	45.91
	Foundation	Footing widening (A1)	m^3	39.88
		Footing widening (P1)	m^3	80.09
		Footing widening (A2)	m^3	50.64
		Install gabion box (P1)	m^2	504.00

Table 12.1.3. Bridge No. 7 Rio Azufrado (R.1)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	Slab thickness increase	m^3	23.00
	Main girder	Steel plate bonding	m^2	46.80
		Girder height increase	m^3	3.94
	Accessory	New installation of expansion joint	m	17.78
		Asphalt paving & waterproofing	m^2	295.01
Substructure	Pier	Concrete jacketing (P1 & P2)	m^3	2 x 19.60
	Foundation	Footing widening (P1 & P2)	m^3	2 x 29.00

Table 12.1.4. Bridge No. 12 Rio Puerto Nuevo (R.2)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	FRP bonding (Surface) (Steel bridge section)	2layers/m^2	436.50
		FRP bonding (Bottom) (Steel bridge section)	2layers/m^2	432.30
		FRP bonding (Surface) (RC bridge section)	2layers/m^2	77.20
		FRP bonding (Bottom) (RC bridge section)	2layers/m^2	76.30
	Main girder	PC cable (3@70ft section of steel bridge)	m	312.00
		PC cable (80ft section of steel bridge)	m	120.00
		Steel plate bonding (RC bridge section)	m^2	42.60
	Prevention system for unseating	Bridge seat widening (A1)	m^3	1.91
		Bridge seat widening (P1 & P2)	m^3	2 x 0.20
		Bridge seat widening (P3)	m^3	0.28
		Bridge seat widening (P4)	m^3	1.43
		Bridge seat widening (A2)	m^3	3.10
		Connection system (chain type)	no	32.00
	Accessory	New installation of expansion joint	m	53.40
		Asphalt paving & waterproofing	m^2	982.80
Substructure	Pier	Height of transversal beam increase (P1-P4)	m^3	4 x 11.92
	Foundation	Footing widening (P1)	m^3	43.43
		Footing widening (P2)	m^3	5.36
		Footing widening (P3)	m^3	19.79
		Footing widening (P4)	m^3	13.66
		Footing widening (A2)	m^3	5.60
		Install gabion box (P1)	m^2	324.00
		Wet masonry (A1)	m^3	150.00

Table 12.1.5. Bridge No. 16 Rio Nuevo (R.2)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	Slab thickness increase	m^3	36.95
	Main girder	FRP bonding-1	6layers/m^2	14.30
		FRP bonding-2	1layer/m^2	289.55
		Reconstruction of crossbeam	m^3	1.84
	Prevention system for unseating	Bridge seat widening (A1)	m^3	6.80
		Bridge seat widening (A2)	m^3	5.45
	Accessory	New installation of expansion joint	m	17.78
		Asphalt paving & waterproofing	m^2	521.29
Substructure	Foundation	Footing widening (A1)	m^3	91.03
		Footing widening (P1)	m^3	33.11
		Footing widening (P2)	m^3	27.96
		Additional pile installation (A1)	m	160.00
		Install gabion box (A1)	m^2	60.00
		Install gabion box (P1 & P2)	m^2	1126.00
		Install gabion box (A2)	m^2	60.00
		Wet masonry (A1)	m^3	225.00
		Wet masonry (P1 & P2)	m^3	60.00
		Wet masonry (A2)	m^3	225.00

Table 12.1.6. Bridge No. 17 Rio Chirripo (R.4)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Accessory	Replacement of expansion joint	m	20.40
		Replacement of asphalt pavement & waterproofing	m^2	1,793.16
Substructure	Pier	Rolling stone protection (P1 & P2)	m^3	2 x 20.44
	Foundation	Footing widening (P1 & P2)	m^3	2 x 24.55

Table 12.1.7. Bridge No. 19 Rio Sarapiqui (R.4)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	FRP bonding (Surface)	2layers/m^2	458.00
		FRP bonding (Bottom)	2layers/m^2	478.70
	Main girder	PC cable (support)	m	409.60
		PC cable (center span)	m	102.40
		Steel plate bonding	m^2	42.60
		Steel plate replacement	ton	34.32
	Prevention system for unseating	Bridge seat widening (A1 & A2)	m^3	2 x 2.43
		Connection system (chain type)	no	10.00
	Accessory	New installation of expansion joint	m	14.60
		Asphalt paving & waterproofing	m^2	726.79
Substructure	Pier	Height of transversal beam increase (P1 & P2)	m^3	2 x 5.51
	Foundation	Footing widening (P1)	m^3	87.40
		Footing widening (P2)	m^3	86.80
		Additional pile installation (P1)	m	239.40

Table 12.1.8. Bridge No. 20 Rio Sucio (R.32)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Accessory	Replacement of expansion joint	m	19.40
		Replacement of asphalt pavement & waterproofing	m^2	1,816.33
Substructure	Pier	Rolling stone protection (P1 & P2)	m^3	2 x 6.48

Table 12.1.9. Bridge No. 26 Rio Chirripo (R.32)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	FRP bonding (Surface)	2layers/m^2	2,158.20
		FRP bonding (Bottom)	2layers/m^2	2,470.30
	Prevention system for unseating	Bridge seat widening (P1)	m^3	11.10
		Bridge seat widening (P7)	m^3	16.36
		Bridge seat widening (A2)	m^3	2.16
		Connection system (chain type)	no	16.00
	Accessory	New installation of expansion joint	m	30.96
		Asphalt paving & waterproofing	m^2	3,527.84
Substructure	Pier	Height of transversal beam increase (P4)	m^3	8.94
	Foundation	Footing widening (P1 & P7)	m^3	2 x 63.30
		Footing widening (P2 & P6)	m^3	2 x 77.67
		Footing widening (P3, P4 & P5)	m^3	3 x 109.58

Table 12.1.10. Bridge No. 29 Rio Torres (R.218)

Member	Sub-Member	Work Description	Unit	Quantity
Superstructure	Slab	Slab thickness increase (30m section)	m^3	12.80
		Slab thickness increase (2@17m section)	m^3	14.50
	Main girder	FRP bonding-1	4layers/m^2	94.10
		FRP bonding-2	1layer/m^2	654.50
	Prevention system for unseating	Bridge seat widening (A1)	m^3	6.24
		Bridge seat widening (P1)	m^3	8.95
		Bridge seat widening (P2)	m^3	4.24
		Bridge seat widening (A2)	m^3	6.09
	Accessory	New installation of expansion joint	m	44.32
		Asphalt paving & waterproofing	m^2	165.10
Substructure	Pier	Concrete jacketing (P1)	m^3	12.01
		Height of transversal beam increase (P1 & P2)	m^3	2 x 13.73
	Foundation	Footing widening (A1)	m^3	36.98
		Footing widening (P1)	m^3	39.59
		Footing widening (A2)	m^3	17.55
		Install gabion box (P1)	m^2	324.00

12.1.3 Working Space under Girder

Various types of scaffolds shall be applied for execution of the Project. Types of scaffolds and their appropriate work items are detailed below.

Type-A

This type of scaffold is hanged by chain under superstructure. Preparation and setting of safety facilities (i.e. fence, handrail & safety net) are crucial. Note internal scaffold shall be installed if clearance between bottom of deck slab and floor is over 2m. This type is applied for works for deck slab and girder. Figure 12.1.1. shows structure of this type.

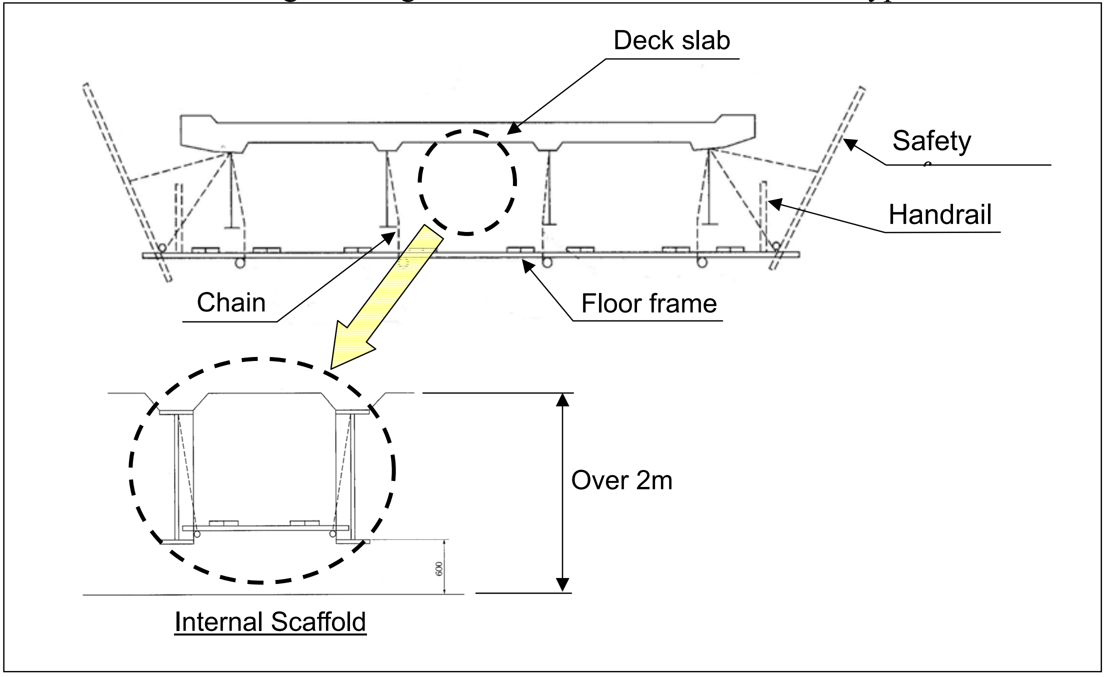


Figure 12.1.1. Scaffold Type-A

Type-B

This type is installed on the side of superstructure with chain and steel frame. This type is applied for works for handrail and barrier curb. Figure 12.1.2. shows structure of this type.

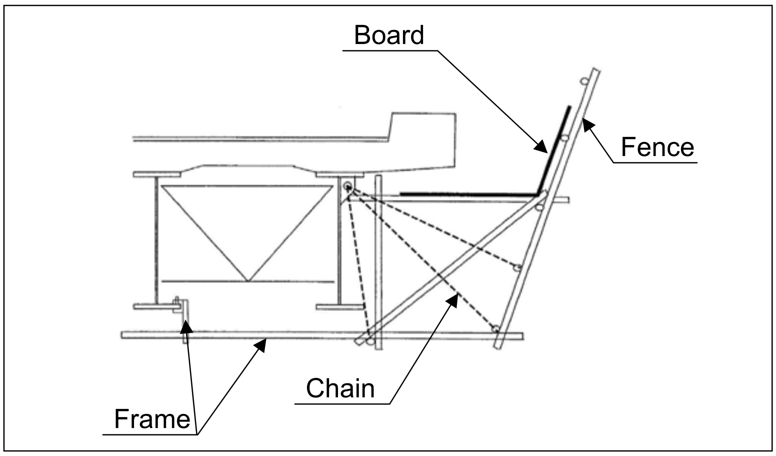


Figure 12.1.2. Scaffold Type-B

Type-C

This type is installed on circumference of pier by chain. This type is applied for works for bearing shoe, unseating prevention system and expansion joint. Figure 12.1.3. shows structure of this type.

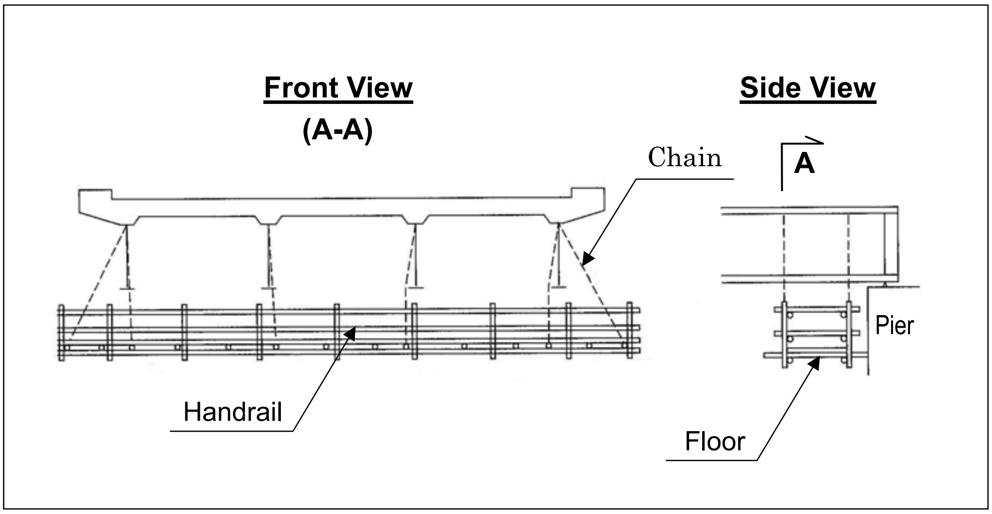


Figure 12.1.3. Scaffold Type-C

Type-D

This type is built to assemble prefabricated frame. This type is applied for works for body of substructure. Figure 12.1.4. shows structure of this type.

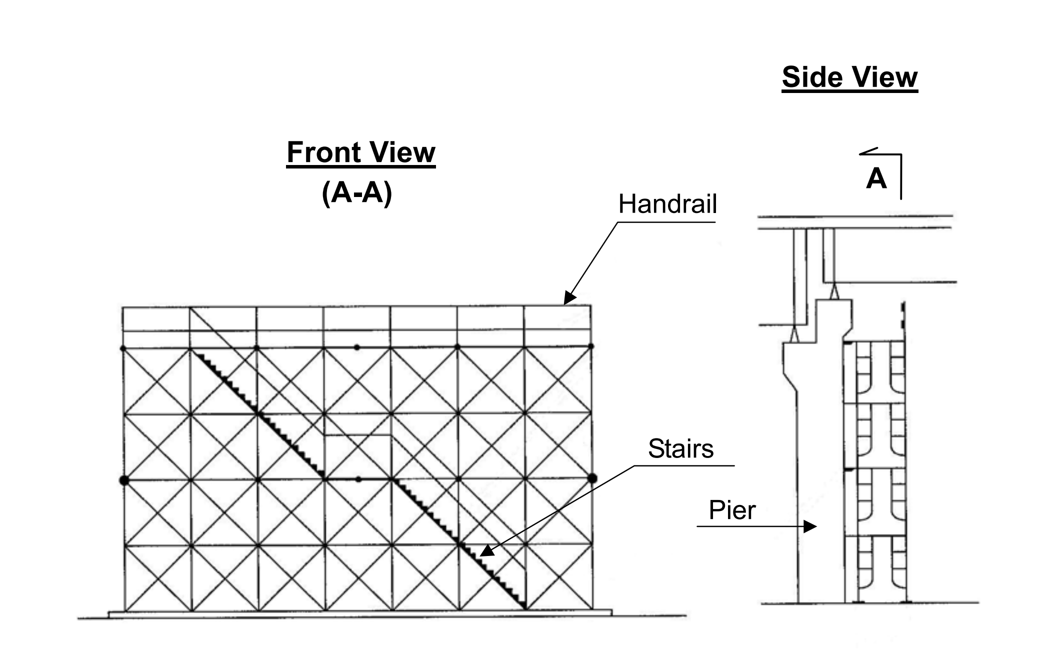


Figure 12.1.4. Scaffold Type-D

12.1.4 Temporary Cofferdam

Temporary cofferdam of large sandbag type (1m^3 /no) shall be constructed in case the work for substructure is executed on riverbed. Further water pump shall be used for drainage in cofferdam. Note this work shall be applied when water level is very low but still remaining during dry season. This work is for Bridge No. 19. Structure model of cofferdam is shown in Figure 12.1.5.

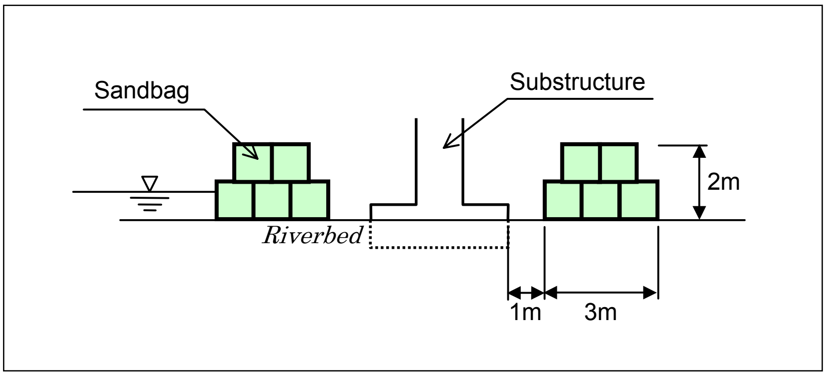


Figure 12.1.5. Structure Model of Cofferdam

12.1.5 Traffic Control

Some of the work items (e.g. replacement of deck slab, asphalt pavement, bonding FRP sheet, etc.) shall progress on bridge surface without traffic flow. On the other hand, negative impact of closing entire traffic during execution period of above works should be considered. Therefore, the works shall be executed on one side of the bridge in order to secure one-way traffic on the other side all the time. For that purpose 4 workers (i.e. 2 on beginning of working area and 2 on the end) shall be assigned for traffic control. General layout of traffic control is shown in Figure 12.1.6.

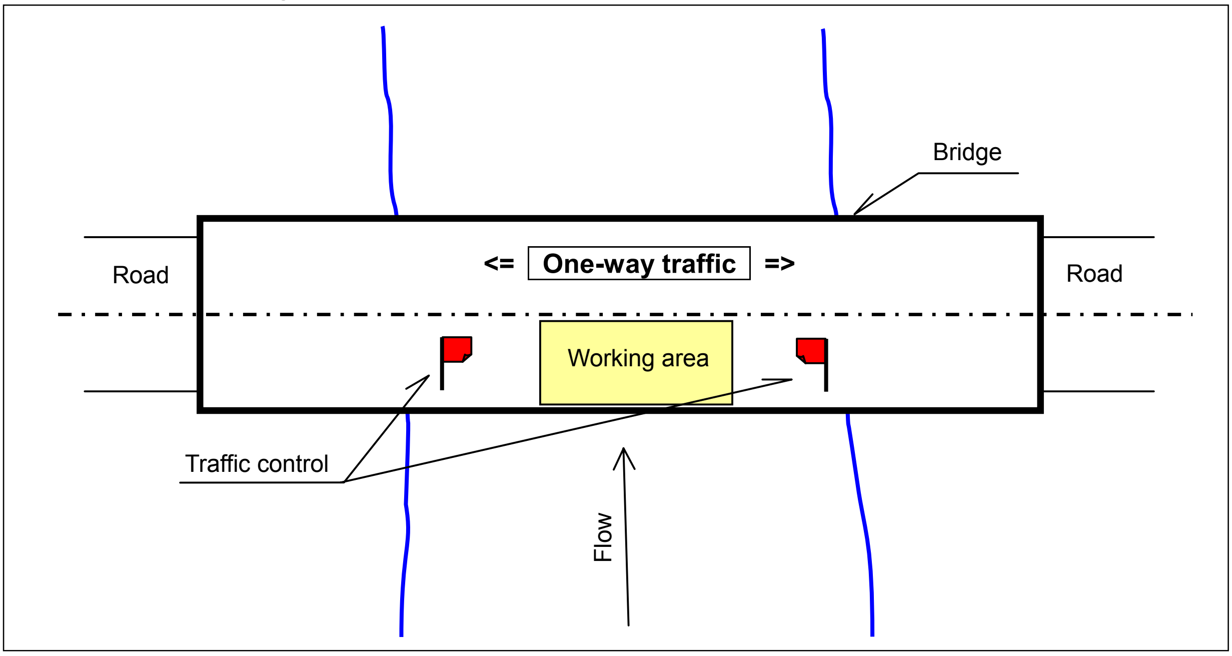


Figure 12.1.6. General Layout of Traffic Control

12.1.6 Temporary Construction Yard

Standard Type

Temporary construction yard shall be prepared during the Project period. The yard is surrounded by barbed wire fence and watched by 2 security guards in 24 hours for security reason. Equipping following facilities is desirable as standard type. This type is applicable for Bridge No. 2, 3, 7, 12, 16, 17, 19 & 26. Layout of this type is shown in Figure 12.1.7.

- Trailer house for engineers/supervisors
- Workshop for in-situ work (5m*10m)
- Shed for material & small equipment (5m*10m)
- 3 parking lots for heavy equipment
- Security booth
- Portable toilet

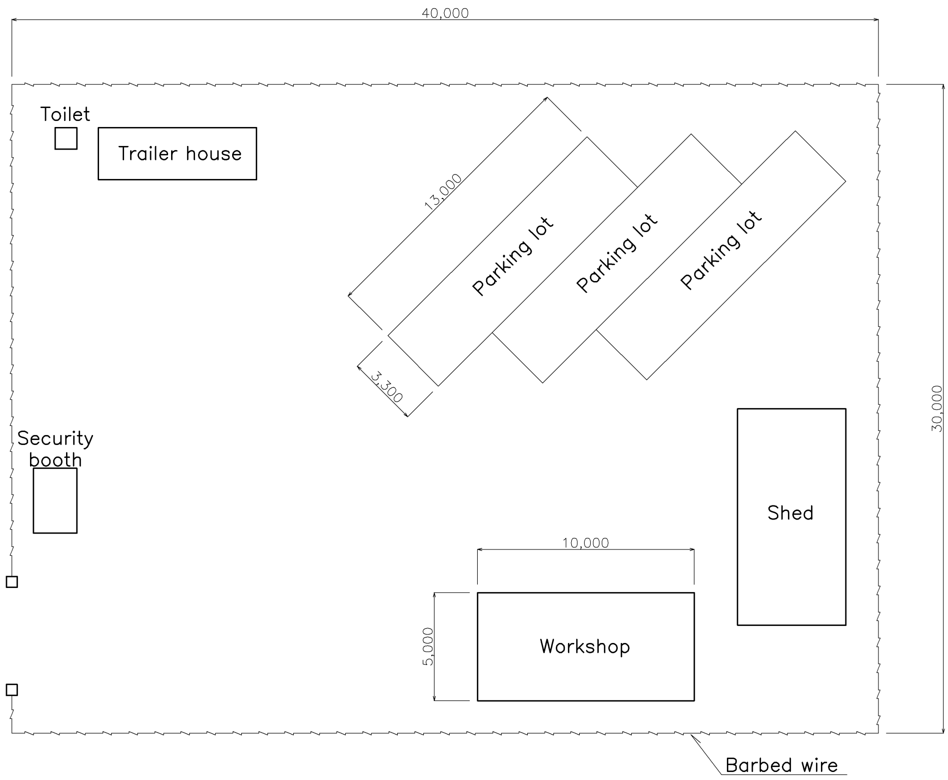


Figure 12.1.7. Layout of Standard Type Construction Yard

<u>**The sites with limitation of land (Bridge No. 20 & 29)**</u>

Unlike other 8 bridges, Bridge No. 20 (Rio Sucio) and No. 29 (Rio Torres) have difficulties to secure sufficient area for the yard. Regarding No. 20, it is hard to obtain flat landform near the bridge except cutting slope beside the road. However, this method is not appropriate because the bridge is located in national park. Regarding No. 29, the bridge is located at densely populated area in San Jose. Therefore, newly construction of the yard is very difficult.

Considering above situation, temporary storage area for equipment and material shall be prepared beside the working area on the bridge. Model layouts for 2 bridges are shown in Figure 12.1.8 and 12.1.9.

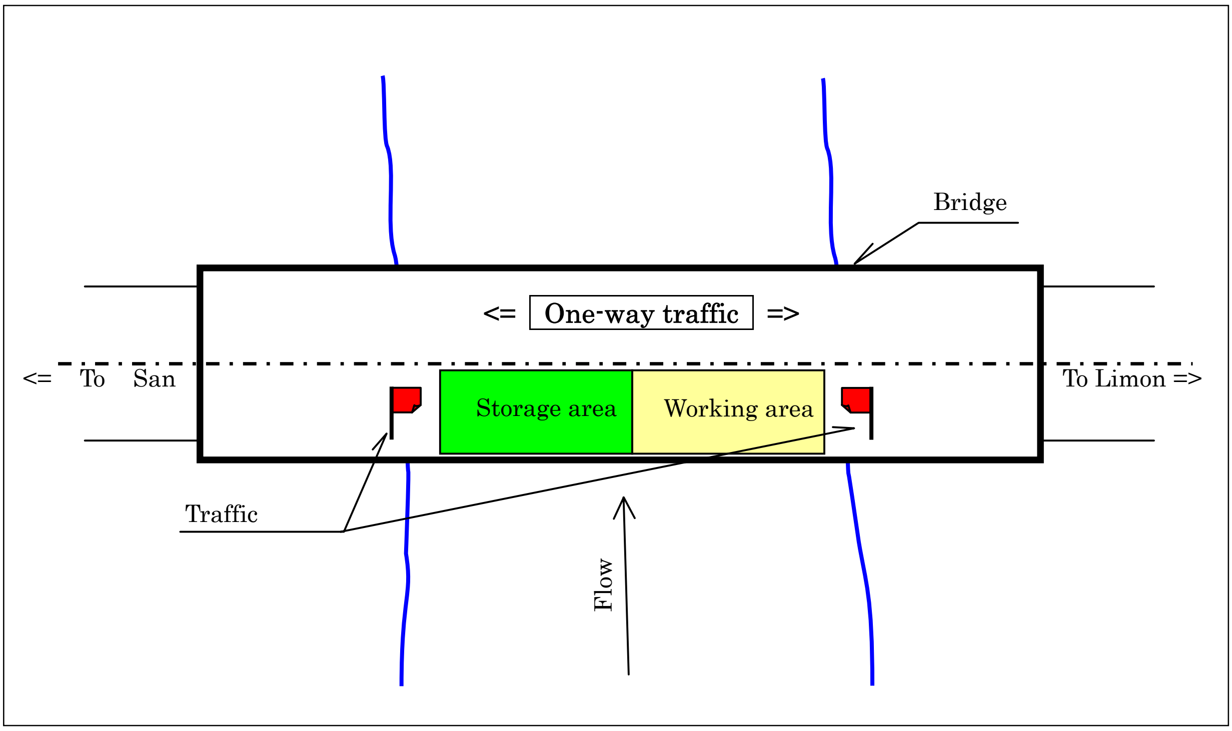


Figure 12.1.8. Model Layout of Storage Area on No. 20 Bridge (Rio Sucio)

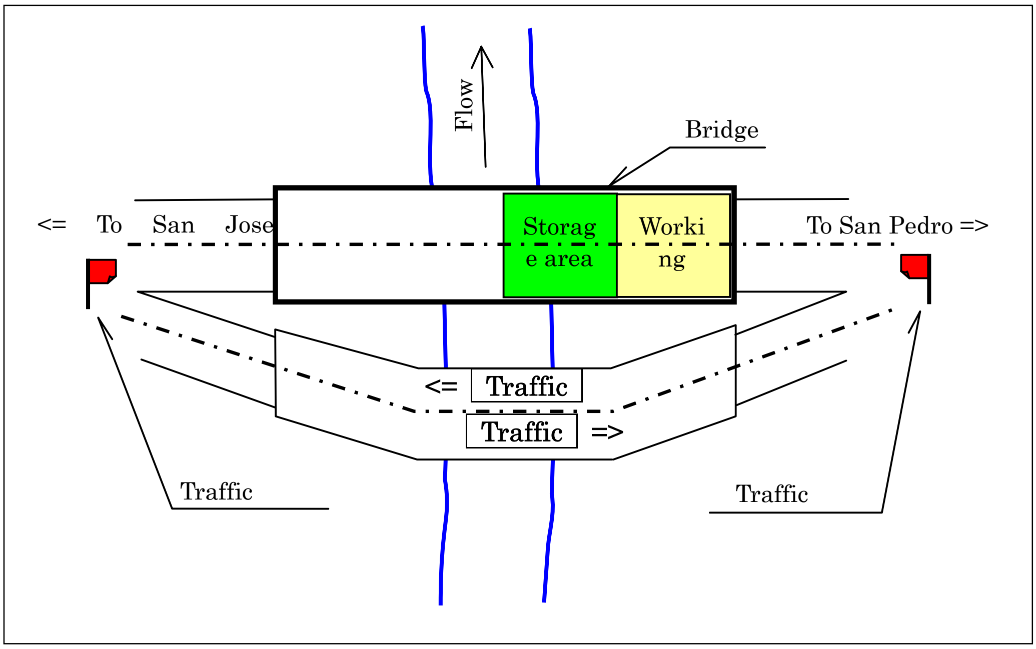


Figure 12.1.9. Model Layout of Storage Area on No. 29 Bridge (Rio Torres)

12.1.7 Construction Schedule

As a result of above discussion, construction period of 10 bridges are shown in Table 12.1.11. Further their construction schedules are attached in Appendix-12.1.

Table 12.1.11. Construction Period of 10 Bridges

Rt.	No.	Name	Period (days)
1	2	Rio Aranjuez	120
	3	Rio Abangares	140
	7	Rio Azufrado	100
2	12	Rio Puerto Nuevo	190
	16	Rio Nuevo	140
4	17	Rio Chirripo	80
	19	Rio Sarapiqui	160
32	20	Rio Sucio	60
	26	Rio Chirripo	145
218	29	Rio Torres	140

12.2 Preliminary Cost Estimate

12.2.1 General

Preliminary cost estimate for the Project is on the basis of design result (i.e. selected work items and their quantities) and construction planning (i.e. construction schedule). Cost for the Project is composed of following items.

Direct Cost

- Construction Cost
  - Preparation and removal of temporary site facility
  - Traffic control in construction period
  - Work execution cost
  - Transportation cost of equipment & material

Indirect Cost

- Contingency Cost
- Administration Cost
- Contractor's Profit

12.2.2 Conditions for the Cost Estimate

1) Exchange Rate

Currency exchange rate for the estimate is applying average of August 2006 according to Banco Central de Costa Rica (Costa Rican Colone <=> U.S. Dollar) and Bank of Tokyo-Mitsubishi UFJ (Japanese Yen <=> U.S. Dollar). The applied rates are shown below.

1 USD =	515.86	CRC
1 USD =	116.91	JPY
1 CRC =	0.23	JPY

Note: CRC = Costa Rican Colone, JPY = Japanese Yen & USD = U.S. Dollar

2) Unit Cost

Unit costs consist of labor, material and construction equipment are applying the data provided by CONAVI. These data are utilized to estimate costs of road maintenance

projects implemented by CONAVI. Each type of unit cost is detailed as follows.

(1) Labor

Unit hourly salary is calculated as follows.

A = Basic salary + (Portion of social welfare (47% of basic salary))

Total salary = A × coefficient of skill

Unit hourly salaries are summarized in Table 12.2.1.

Table. 12.2.1. Unit Hourly Salaries of Labors

(Currency: Colone)

CODE	DESCRIPTION	UNIT	BASIC SALARY	WITH 47% OF SOCIAL CHARGE	COEFFICIENT OF SKILL	TOTAL
MOB001	Common worker	hr	590	867	1.00	**867**
MOB002	Blaster	hr	648	953	1.00	**953**
MOB003	Foreman	hr	813	1,194	1.00	**1,194**
MOB004	Mechanic	hr	813	1,194	3.25	**3,882**
MOB005	Assistant worker	hr	590	867	1.00	**867**
MOB006	Bricklayer	hr	648	953	1.00	**953**
MOB007	Carpenter	hr	676	994	1.00	**994**
MOB008	Form worker	hr	648	953	1.00	**953**
MOB009	Welder	hr	676	994	1.00	**994**
MOB010	Painter	hr	590	867	1.00	**867**
MOB011	Security guard	hr	590	867	1.00	**867**
MOB012	Printer	hr	676	994	1.00	**994**
MOB013	Assistant printer	hr	590	867	1.00	**867**
OP001	Operator of excavator	hr	813	1,194	1.00	**1,194**
OP002	Dump truck driver	hr	676	994	1.00	**994**
OP003	Operator of breaker	hr	676	994	1.00	**994**
OP004	Operator of wheel loader	hr	676	994	1.50	**1,491**
OP005	Operator of trailer truck	hr	676	994	1.00	**994**
OP006	Operator of crane	hr	813	1,194	1.00	**1,194**
OP007	Operator of road marker	hr	648	953	1.00	**953**
OP008	Light truck driver	hr	648	953	1.00	**953**
OP009	Operator of bulldozer	hr	813	1,194	1.75	**2,090**
OP010	Operator of scraper	hr	813	1,194	1.00	**1,194**
OP011	Operator of compactor	hr	676	994	1.00	**994**
OP012	Operator of motor grader	hr	813	1,194	2.00	**2,389**
OP013	Operator of retro-excavator	hr	813	1,194	1.00	**1,194**
OP014	Operator of drilling machine	hr	676	994	1.00	**994**
OP015	Operator of asphalt plant	hr	813	1,194	1.00	**1,194**
OP016	Operator of asphalt finisher	hr	813	1,194	1.00	**1,194**
OP017	Operator of concrete mixer	hr	648	953	1.00	**953**
OP018	Operator of concrete paver	hr	813	1,194	1.00	**1,194**

(2) Material

Unit price of construction material includes 13% of sales tax. Unit prices of major materials are summarized in Table 12.2.2.

Table 12.2.2. Unit Prices of Major Materials

(Currency: Colone)

CODE	DESCRIPTION	UNIT	PRICE
MAT064	STEEL FOR STRUCTURES	kg	486
MAT039	POSTENSION STEEL	kg	440
MAT011	REINFORCEMENT STEEL	kg	343
MAT020	ACETYLENE	kg	69,589
MAT059	SPIKES WIRE	m	26
MAT012	BLACK WIRE	kg	466
MAT146	SAND max 4.75mm	m3	5,424
MAT021	STRAIGHT ASPHALT 85/100	ltr	191
MAT013	PORTLAND CEMENT (AGUA CALIENTE FACTORY)	kg	62
MAT008	VARIOUS NAILS	kg	542
MAT009	DIESEL	ltr	288
MAT026	ASPHALT EMULSION	ltr	164
MAT071	GABION 2.40 mm 2 X 0.50 X 1 MESH 8X10	no	11,690
MAT070	GABION 2.40 mm 2 X 1 X 1 MESH 8X10	no	16,930
MAT302	GASOLINE	ltr	389
MAT150	BALLAST (fine) max 38 mm	m3	3,221
MAT999	LUBRICANT (For heavy weight machinery)	ltr	1,272
MAT066	SPECIAL WOOD FOR RAILING	pulg	187
MAT007	WOOD FOR FORMS	pulg	334
MAT028	MATERIAL / JOINT SEAL	kg	1,419
MAT161	ASPHALTIC MIX FROM FACTORY	t	28,250
MAT148	RUBBLE STONE max 250mm	m3	5,481
MAT032	STRUCTURAL STEEL PILE 12X12X53	m	61,444
MAT130	STRUCTURAL STEEL PILE 12X12X74	m	84,271
MAT134	POSTENSED CONCRETE PILE 30X30 PC:MAT-134	m	31,730
MAT034	POSTENSED CONCRETE PILE 35X35 PC:MAT-034	m	47,457
MAT017	STEEL SHEET PILE	m	8,468

In case procurement condition of specific material is uncertain or unreliable in domestic market, market price in Japan is applied after modification for the estimate. Coefficient of modification is decided on price comparison of major construction materials between Costa Rica and Japan. Result of comparison is in Table 12.2.3.

Table 12.2.3. Price Comparison of Major Materials between Costa Rica & Japan

Item	Unit	Price in Costa Rica		Price in Japan		Percentage
		CRC	=> USD	JPY	=> USD	Costa Rica/Japan
Steel for structure	kg	430	0.83	78	0.67	124.9%
Reinforcement bar	kg	303	0.59	57	0.49	120.5%
Portland cement	kg	55	0.11	8.6	0.07	144.9%
Ready mixed concrete (21N)	m3	57,600	111.66	9,490	81.17	137.6%
Straight asphalt (85/100)	ltr	169	0.33	52.5	0.45	73.0%
Asphalt emulsion	ltr	145	0.28	52.3	0.45	62.9%
Average (= Coefficient of Modification)						**110.6%**

Note: Above costs exclude taxes.

(3) Construction Equipment

Unit cost of equipment consists of 2 major items namely fix cost and operation cost. Further these 2 items are divided into several sub-items respectively. Structure of unit cost is as follows.

(i) Fix Cost

- i) Residual value in design life
- ii) Hire cost
- iii) Interest
- iv) Insurance
- v) Tax (13.00% to 52.29% of total amount of Fix Cost)

(ii) Operation Cost

- i) Spare parts
- ii) Fuel
- iii) Lubricant
- iv) Tire
- v) Manpower (mechanic & operator)

Regarding tax, specific percentage of total fix cost is designated as tax portion and its percentage depends on type of equipment. For example, hydraulic excavator, motor grader and wheel loader have 15.97%. On the other hand, dump truck and flatbed truck have 33.69%.

Unit hourly costs of major equipments in 2 cases namely "with tax" and "without tax" are summarized in Table 12.2.4.

Table 12.2.4. Unit Hourly Cost of Major Equipment

(Currency: Colone)

CODE	DESCRIPTION	COMPANY	MODEL	CAPACITY (HP/kW)	DESIGN LIFE (YR)	UNIT COST WITH TAX			UNIT COST WITHOUT TAX		
						FIX COST	OPERATION COST	TOTAL	FIX COST	OPERATION COST	TOTAL
ACA002	CONCRETE PAVER	PAV-SAVER	2232SHF	135 / 101	9.0	32,470	73,205	105,675	28,195	68,930	97,125
AIR001	AIR COMPRESSOR (DISEL)	--	160 cfm	60 / 45	9.0	1,612	7,062	8,674	1,390	6,840	8,230
BAR202	ROAD SWEEPER	BROCE	RJ-350	80 / 60	6.0	5,561	13,680	19,240	4,958	13,077	18,035
BAT001	PORTABLE CONCRETE MIXER (DIESEL)	YANMAR		8 / 6	5.0	329	1,746	2,075	291	1,708	1,999
BOM001	CENTRIFUGAL WATER PUMP (8,000gph) GASOLINE	Encendido manual	2"	7 / 5	9.0	182	2,193	2,375	157	2,168	2,325
CAB002	TRACTOR VEHICLE OF TRAILER (20 ton)	43 000 lbs	6 X 4	235 / 175	7.0	9,315	23,822	33,137	8,196	22,702	30,898
CAM102	FLATBED TRUCK (11 ton)	--	4x2	180 / 134	7.0	7,344	16,319	23,662	5,791	14,766	20,557
CAM202	TANK LORRY (FUEL)	--	6x4	210 / 157	7.0	7,450	19,346	26,797	5,871	17,767	23,638
CAL123	WHEEL LOADER (4WD)	CATERPILLAR	950G	180 / 134	7.0	20,071	39,937	60,008	17,552	37,418	54,970
CAT001	VIBRATORY ASPHALT COMPACTOR	CATERPILLAR	CB 214B	33 / 25	11.0	4,422	10,636	15,058	3,976	10,190	14,166
COL012	PNEUMATIC ASPHALT COMPACTOR	CATERPILLAR	PS-150B	64 / 48	7.0	10,682	25,701	36,383	9,374	24,393	33,767
COP200	SOIL COMPACTOR	CATERPILLAR	815B	210 / 157	9.0	26,592	61,341	87,933	23,094	57,843	80,936
CRL007	VIBRATORY ROLLER	BOMAG	BW172D-2	76.4 / 57	9.0	12,480	21,927	34,407	10,925	20,371	31,296
DIA001	ASPHALT DISTRIBUTOR	--	1600 GALONES	0 / 0	15.0	12,189	22,477	34,666	10,673	20,962	31,636
DAG100	CHIP SPREADER (DIESEL)	ETNYRE	CHIP SPREADER	152 / 113	7.0	8,085	28,956	37,041	7,167	28,039	35,206
FIN101	ASPHALT PAVER (WHEEL)	BARBER GREENE	BG-220B	108 / 81	9.0	29,246	71,770	101,016	25,415	67,939	93,354
FIN103	ASPHALT PAVER (CRAWLER)	CATERPILLAR	AP-1050	145 / 108	9.0	42,245	102,379	144,624	36,624	96,758	133,382
GEN020	GENERATOR 20 kw	Genérico	Diesel	33 / 25	10.0	1,299	6,275	7,574	1,120	6,096	7,217
GEN100	GENERATOR 100 kw	Genérico	Diesel	143 / 107	10.0	2,109	17,242	19,351	1,819	16,952	18,770
GEN950	GENERATOR 1,000 kw	Genérico	Diesel	1425 / 1063	10.0	21,191	160,592	181,783	18,273	157,674	175,947
GRU050	TRUCK CRANE 8x4 40,0 ft (31,8 tm)	LINK-BELT	HC-78B	84 / 63	10.0	42,298	63,405	105,704	36,670	57,777	94,447
GRU101	ROUGH TERRAIN CRANE (15TON)	GROVE	RT58E	130 / 97	7.0	20,400	37,196	57,596	17,787	34,583	52,370
GRU202	CRAWLER CRANE (110TON)	LINK-BELT	LS-218H	247 / 184	15.0	36,419	63,867	100,286	31,601	59,048	90,649
MOT400	SCRAPER (34 CY, 26 m3) EROPS	CATERPILLAR	633E	475 / 354	9.0	56,678	120,780	177,458	49,070	113,172	162,242
NIR101	MOTOR GRADER (RIGID)	CHAMPIÓN	720	160 / 119	9.0	14,533	33,269	47,802	12,924	31,659	44,583
NIV098	MOTOR GRADER (ARTICULACY)	KOMATSU	GD 530A-2C	144 / 107	9.0	14,556	31,967	46,522	12,943	30,354	43,297
PAL099	HYDRAULIC EXCAVATOR (20.6 TM)	CATERPILLAR	320BL	128 / 95	7.0	23,301	44,876	68,177	20,289	41,863	62,152
PLA103	ASPHALT PLANT (162-356 tph; 7´4" x 35´0")	CEDARAPIDS	8835	193 / 144	10.0	70,169	107,032	177,201	60,703	97,567	158,270
QPR101	PRIMAL CRUSHER (mandivula; 21"x48"; alimentador 42"x14´)	PIONEER	SM-2148	125 / 93	7.0	49,320	102,033	151,354	42,693	95,405	138,098
QSE100	SECONDARY CRUSHER (cono 40"; banda 48"x12´)	KUE-KEN	40 CT-412	155 / 116	7.0	32,061	66,790	98,850	27,809	62,538	90,348
QCO001	CONE CRUSHER	---	36"	75 / 56	7.0	16,999	36,031	53,031	14,822	33,854	48,675
RET010	BACKHOE LOADER (WHEEL) 2WD	CASE	580-L	70 / 52	8.0	8,254	15,923	24,176	7,313	14,982	22,295
TAG200	CONCRETE AGITATOR TRUCK (6 m3)	--	---	235 / 175	8.0	13,408	43,504	56,913	11,704	41,800	53,505
TRA110	BULLDOZER (EROPS)	CATERPILLAR	D6R	165 / 123	7.0	20,341	43,916	64,257	17,883	41,458	59,341

3) Calculation of Unit Cost of Work Item

(1) Applying Standard of Cost Estimate

Following standards are utilized to estimate unit cost of work item for the Project. Generally, Costa Rican standard is preferred in case both countries have a method to estimate of a certain work item (e.g. formwork, re-bar work, soil excavation work etc.).

Costa Rica

- LICITACION RESTRINGIDA PARA LA CONTRATACION DE LOS SERVICIOS DE UN CONSULTOR PARA LA ACTUALIZACION Y MODERNIZACION DEL SISTEMA DE COSTOS DE OBRAS VIALES DEL AREA DE VIALIDAD
  - INFORME FINAL
  - FORMULACION DE RENGLONES DE PAGO TOMO I, II, III & IV
  - TABLAS

Japan

- CIVIL WORK COST ESTIMATE STANDARD OF MINISTRY OF LAND, INFRASTRUCTURE & TRANSPORT (2005)
- CIVIL WORK COST ESTIMATE STANDARD OF JAPAN HIGHWAY (2005)
- COST ESTIMATE STANDARD OF BRIDGE CONSTRUCTION (2005)
- CIVIL WORK STANDARD COST ESTIMATE METHOD (42TH REV.)
- CIVIL WORK COST ESTIMATE METHOD HANDBOOK (2005)
- CALCULATION TABLE OF HIRE COST OF CONSTRUCTION EQUIPMENT (2003)
- COST ESTIMATE MANUAL OF BRIDGE REINFORCING WORK BY OUT CABLE METHOD (2004)
- GUIDE OF UNIT PRICE OF CONSTRUCTION MATERIAL (MAY/2006)

(2) Modification of Unit Cost

(i) Labor

In case of applying Japanese standard, required number of labor (e.g. foreman, skill worker, common worker etc.) of each work item shall be modified depending of regional conditions shown in Table 12.2.5. This method is in accordance with cost estimate work for Japan's grant aid project.

Table 12.2.5. Modification Coefficient of Number of Labor

Region	Common Work	Skilful Work
Asia	1.5 times of worker's number in Japanese standard	2.5 times of worker's number in Japanese standard
Africa	2.0	3.5
Central & South America	1.5	2.5
Oceania	2.5	4.0
Middle East	2.0	3.5
East Europe	1.2	1.5

(ii) Portion of Sundry Expenses

Generally there is a portion for sundry expenses in unit work item in Japanese standard. This portion is prepared for expenses of minor works, equipments and materials included in the work item. And that is calculated as percentage of total labor cost in almost of the cases. For example, 15% of total labor cost is prepared to spend for chisel, steel cutter, oxygen and acetylene in unit cost of "removal of expansion joint".

However, amount for the portion is insufficient in case of applying unit salary of Costa Rican labor stated in Table 12.2.1. because of salary gap between Costa Rica and Japan. Table 12.2.6. shows comparison of unit salary between Costa Rica and Japan.

Table 12.2.6. Comparison of Unit Hourly Salary between Costa Rica & Japan

Type of Labor	Salary in Costa Rica		Salary in Japan		Percentage
	CRC	=> USD	JPY	=> USD	JP/CR
Common worker	867	1.68	1,637	14.00	833%
Foreman	1,194	2.31	2,385	20.40	881%
Carpenter	994	1.93	2,150	18.39	954%
Form worker	953	1.85	2,097	17.94	970%
Average of operator	1,247	2.42	2,096	17.93	741%
				Average	**876%**

On the other hand, number of labor in unit cost of work item has already been modified in accordance with Table 12.2.5. Therefore, portion of sundry expenses shall be modified as follows;

Common work : (Total cost of Costa Rican labor) × <u>584%</u> (*1)

Skilful work : (Total cost of Costa Rican labor) × <u>350%</u> (*2)

(*1) 876% ÷ 150% = <u>584%</u>

(*2) 876% ÷ 250% = <u>350%</u>

(3) Unit Cost of Work Item

Applying unit costs of major work items by referring above described standards and modification methods are summarized in Table 12.2.7. and a breakdown of a sample work item called "Removal of expansion joint" is shown in Table 12.2.8. Further, full list and breakdown of each item are attached in Appendix-12.

Table 12.2.7. Unit Costs of Major Work Items

Work Item	Unit	Cost (USD)	Standard
Injection & filling on concrete surface	m (crack length)	10.28	Japan
Removal of existing pavement	m^3	27.55	Japan
Removal of handrail	m^3	7.02	Japan
Chipping work on concrete surface	m^2	15.31	Japan
Drilling hole on steel member	no	2.67	Japan
Pasting carbon fiber sheet on deck slab	2layers/m^2	308.75	Japan
Replacement of bearing shoe (Fix) (including material cost)	no	14,806.72	Japan
Replacement of expansion joint (including material cost)	m	1,139.25	Japan
Waterproofing of deck slab (painting method)	m^2	105.30	Japan
Install gabion box (2m*1m*1m)	m	230.18	Japan
Formwork (including material cost)	m^2	5.11	Costa Rica
Arrangement of re-bar (including material cost)	kg	1.08	Costa Rica
Demolition of concrete structure	m^3	109.36	Costa Rica
Paving asphalt surface course	m^3	136.71	Costa Rica
Excavation for structure (soil)	m^3	2.84	Costa Rica
Casting concrete & curing (225kg/cm2)	m^3	154.27	Costa Rica
Install steel handrail	m	100.00	Costa Rica
Pile driving work (H-steel)	m	274.19	Costa Rica
Wet masonry work	m^3	63.40	Costa Rica

Table 12.2.8. Breakdown of Work Item "Removal of Expansion Joint"

Removal of expansion joint

Work Description: Disassembling & removal of existing expansion joint

CODE: C008.8

per 10.00 m

P940 Tab.4-20 Cost estimate of bridge construction (JPN) 2005

Item	Spec.	Unit	Qty	Unit Price			Total Amount			Remarks
				CRC	USD	JPY	CRC	USD	JPY	
Foreman	1.00day x 2.50 x 8hrs	hr	20.00	1,194			23,880			MOB003
Skilled worker	4.00day x 2.50 x 8hrs	hr	80.00	994			79,520			MOB014
Common worker	1.00day x 2.50 x 8hrs	hr	20.00	867			17,340			MOB001
FLATBED TRUCK (7 ton)	1.70day x 5.31hrs (with 2.9t crane)	hr	9.03	18,462			166,656			Std. operation hour = 850hrs/yr ÷160day/yr =5.31hrs/day
AIR COMPRESSOR (DISEL)	1.40day x 8hrs	hr	11.20	8,674			97,149			3.5-3.7m3/min
CONCRETE CUTTER	1.40day x 8hrs	hr	11.20	11,992			134,310			30kg
Sundry Expenses	Cost for chisel, steel cutter, oxygen, acetylene & fuel	time	3.50				63,389			15% of total labor cost (JPN)
Sub Total of 10m							582,243			
Removal of expansion joint	Disassembling & removal of existing expansion joint	m					58,224			$112.87

Modified coefficient (Tab. 12.2.5)

Modified coefficient

Contents of expense

Modified amount for sundry expenses

Original designated percentage

12.2.3 Project Cost Estimate

1) Direct Cost

Basically direct cost is estimated according to unit costs of work items for rehabilitation and their corresponding quantities. However, regarding transportation cost for material and equipment, procurement conditions of them (e.g. distance between site and supplier, quarry, borrow pit etc.) are various because locations of target bridges are spread out in the country. Therefore, transportation cost of the Project is applying averaged percentage of direct cost among sample projects implemented by MOPT in the past. The percentages of sample projects are shown in Table 12.2.9. 5% of total direct cost is applied for the transportation cost in the Project.

Table 12.2.9. Percentage of Transportation Costs among Sample Projects

Sample No.	Total Direct Cost	Transportation	Other Cost
1	1,131,361	49,690 (4.4%)	1,081,671 (95.6%)
2	981,332	47,830 (4.9%)	933,502 (95.1%)
3	1,329,638	52,235 (4.1%)	1,277,402 (95.9%)

2) Indirect Cost

Generally, costs in this category namely contingency cost, administration cost and contractor's profit have been estimated according to percentage of total direct cost by project implementation agency (e.g. CONAVI, MOPT). Their percentages are various depending on project's budget scale. Applying percentages for the Project are decided as follows on the basis of analysis of previous projects and discussion with counterparts.

(a) Contingency Cost: 5% of total direct cost

(b) Administration Cost: 10% of {total direct cost + (a)}

(c) Contractor's Profit: 10% of {total direct cost + (a) + (b)}

3) Result of Cost Estimate

The Project cost estimate for 10 selected bridges are finalized in Table 12.2.10. Further, their breakdown lists are attached in Appendix-12.2.

Table 12.2.10. Project Cost Summary

Summary | Basic Data: Total project costs of 10 bridges | CODE: SUM000

per 1.00 Ls

Item	Spec.	Unit	Qty	Unit Price			Total Amount			Equivalent (USD)	Remarks
				CRC	USD	JPY	CRC	USD	JPY		
No.2 Rio Aranjuez (1 of 2)	Rt.1, Steel truss, L=87.78m, Completion in 1955	site	1.00	287,241,753		30,285,792	287,241,753		30,285,792	$815,873.33	RT001.02.1
No.2 Rio Aranjuez (2 of 2)	Rt.1, Steel truss, L=87.78m, Completion in 1955	site	1.00	220,201,030	26,713	2,558,910	220,201,030	26,712.52	2,558,910	$475,462.37	RT001.02.2
No.2 Rio Aranjuez Total							**507,442,784**	**26,712.52**	**32,844,701**	**$1,291,335.71**	
No.3 Rio Abangares (1 of 2)	Rt.1, Steel thru truss, L=101.34m, Completion in 1953	site	1.00	309,068,365		29,292,663	309,068,365		29,292,663	$849,689.64	RT001.03.1
No.3 Rio Abangares (2 of 2)	Rt.1, Steel thru truss, L=101.34m, Completion in 1953	site	1.00	198,340,941	107,080	3,555,149	198,340,941	107,079.52	3,555,149	$521,974.79	RT001.03.2
No.3 Rio Abangares Total							**507,409,306**	**107,079.52**	**32,847,813**	**$1,371,664.42**	
No.7 Rio Azufrado	Rt.1, Rigid reinforced concrete frame, L=31.39m, Completion in 1955	site	1.00	117,281,252	80,042	14,608,995	**117,281,252**	**80,041.50**	**14,608,995**	**$432,351.76**	RT001.07
No.12 Rio Puerto Nuevo (1 of 2)	Rt.2, Steel beam & reinforced concrete girder, L=104.89m, Completion in 1961	site	1.00	78,904,061		72,287,237	78,904,061		72,287,237	$771,271.60	RT002.12.1
No.12 Rio Puerto Nuevo (2 of 2)	Rt.2, Steel beam & reinforced concrete girder, L=104.89m, Completion in 1961	site	1.00	265,831,855	40,021	5,210,845	265,831,855	40,020.75	5,210,845	$599,910.01	RT002.12.2
No.12 Rio Puerto Nuevo Total							**344,735,916**	**40,020.75**	**77,498,082**	**$1,371,181.61**	
No.16 Rio Nuevo	Rt.2, Continuous reinforced concrete girder, L=55.47m, Completion in 1961	site	1.00	280,730,856		13,694,389	**280,730,856**		**13,694,389**	**$661,335.87**	RT002.16
No.17 Rio Chirripo	Rt.4, Concrete box girder, L=175.80m, Completion in 1978	site	1.00	226,420,000		5,438,424	**226,420,000**		**5,438,424**	**$485,435.57**	RT004.17
No.19 Rio Sarapiqui	Rt.4, Steel I-beam, L=100.96m, Completion in 1978	site	1.00	261,206,357		70,312,715	**261,206,357**		**70,312,715**	**$1,107,777.26**	RT004.19
No.20 Rio Sucio	Rt.32, Concrete box girder, L=187.25m, Completion in N.A.	site	1.00	163,653,216		4,996,830	**163,653,216**		**4,996,830**	**$359,984.29**	RT032.20
No.26 Rio Chirripo (1 of 2)	Rt.32, Continuous steel I-beam, L=431.90m, Completion in 1974-1978	site	1.00	52,217,159		222,143,100	52,217,159		222,143,100	$2,001,344.11	RT032.26.1
No.26 Rio Chirripo (2 of 2)	Rt.32, Continuous steel I-beam, L=431.90m, Completion in 1974-1978	site	1.00	610,636,845		9,966,921	610,636,845		9,966,921	$1,268,978.84	RT032.26.2
No.26 Rio Chirripo Total							**662,854,005**		**232,110,021**	**$3,270,322.96**	
No.29 Rio Torres (1 of 2)	Rt.218, Concrere pos-tensioned I-girder, L=66.46m, Completion in N.A.	site	1.00	34,044,448		24,762,335	34,044,448		24,762,335	$277,802.34	RT218.29.1
No.29 Rio Torres (2 of 2)	Rt.218, Concrere pos-tensioned I-girder, L=66.46m, Completion in N.A.	site	1.00	130,581,768		3,057,081	130,581,768		3,057,081	$279,283.14	RT218.29.2
No.29 Rio TorresTotal							**164,626,216**		**27,819,416**	**$557,085.47**	
Summary	**Total project costs of 10 bridges**	**Ls**					**3,236,359,907**	**253,854.29**	**512,171,387**	**$10,908,474.93**	

CHAPTER 13 ECONOMIC ANALYSIS

13.1 Introduction

13.1.1 Objective & Condition

In the stage of Scope of Work and Minute of Meeting, the economic analysis has not been indicated. In general, the economic analysis method for new road construction is established and formulated, but for rehabilitation & reinforcement especially for bridges has not been established, it is still under academic study.

Within the above background, the aim of this economic analysis includes subjects such as: 1) consideration of the suitable economic analysis method for bridge rehabilitation & reinforcement, 2) trial this analysis against the 10 selected bridge, and 3) systemized this method to be extended to another bridge.

13.1.2 The Concept of Economic Analysis for Bridge Rehabilitation & Reinforcement

In order to reach above objective, the concept of economic analysis has been set-up as below.

- To review the method of economic analysis for infrastructure construction especially for roads and to make proposals for the suitable method of economic analysis for bridge rehabilitation & reinforcement.

- To consider that this result will be possible to be used for the materials applied to society and road users to understand and become aware about the importance of bridge maintenance. This might help the module project 5 in the capacity development context.

- To conduct the economic analysis mainly as how much benefit and cost will be estimated when the set of rehabilitation and reinforcement is implemented to each selected bridge.

During the study period, two feasibility study reports have been collected for reference to economic parameter. These are conducted by CNC for the concession project of roads and their project name are *"Diseno Preliminar y Estudio de Factibilidad para la Concesion de Obra con Servicio Publico de la Carretera Braulio Carrillo (San Jose – Guapiles – Limon) 2001. 6"* and *"Diseño Preliminar Y Estudio De Factibilidad Técnica, Social, Ambiental, Económica Y Financiera Para La Concesión De Obra Con Servicio Público De Las Secciones A, B Y D Del Proyecto Anillo Periférico De San José De Costa Rica 2004.10"*.

13.1.3 Project Costs & Benefits for Bridge Rehabilitation & Reinforcement

Based on the "with case" and "without case" for bridge rehabilitation & reinforcement, project costs & benefits are thought as table below. The project benefits are evaluated as the reduction costs which are the costs in the case of "without case". Note that the costs in without case is estimated under the scenario which will be happen when the bridge will not be rehabilitated & reinforced in the future.

Table 13.1.1. Basic Concepts of Costs & Benefits

	With Case	Without Case
Scenario	To conduct Rehabilitation & Reinforcement -> To extend the life of the bridge -> to have ability of Anti-Semitic	Not to conduct Rehabilitation & Reinforcement -> To became unusable when the bridge has reached its life -> The bridge falls down if an earthquake occurs
Cost	Cost 1: Work Cost for Rehabilitation & Reinforcement Cost 2: Social Cost due to Detour by traffic closure or Waiting by traffic restriction	Type A: Scenario caused by Bridge Life Cost 1: Work Cost for Reconstruction Cost 2: Social Cost Detour Cost due to traffic closure in construction period Type B: Scenario caused by Earthquake Cost 1: Work Cost for Emergency Recovery & Reconstruction Cost 2: Social Cost Detour Cost due to traffic closure in construction period
Project Benefit	Reduction of Costs in Without Case	

According to this concepts, the characteristics of Costs & Benefits appearance is shown below. It is clear that the benefits appear only when the events occurred under the scenario due to bridge life & earthquake. These benefits have the characteristics as below.

- Benefits due to the bridge's life will appear at "once" when the scenario occurs.

- Benefits due to earthquake will appear at "each year" because there are a probability of earthquake occurrence.

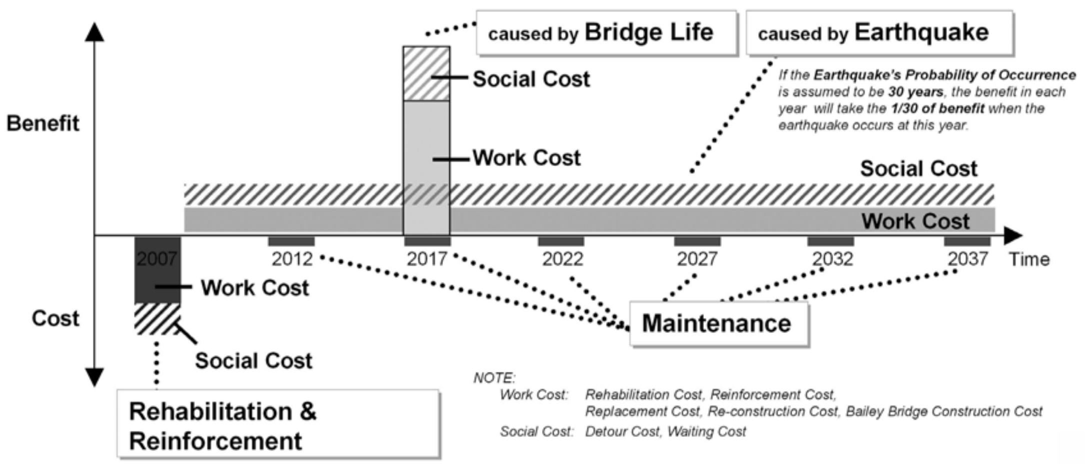


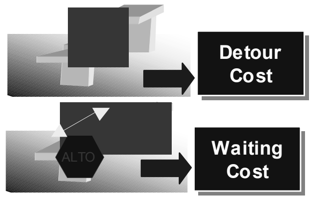
Figure 13.1.1. Image of Costs & Benefits Appearance

This study takes 30 years for evaluation period because its scenario ,especially earthquake, will occur within 30 to 50 years and most of bridge life is within 30 years.

Following section will describe how the Social Costs & Benefits will be estimated and its results, then Work Cost will be described later, economic analysis such as EIRR & B/C will be taken at last.

13.2 Social Costs & Benefits

13.2.1 Work Flow for estimation of Social Costs & Benefits



In order to estimate the Social Costs & Benefits for bridge rehabilitation & reinforcement, it is necessary that what kind of items should be included. This study takes the Social Costs as the "Detour Cost" & "Waiting Cost" due to traffic closure & restriction. Detour Cost is raised when the bridge falls down and there are detour route. Waiting Cost is raised when the traffic restriction for one-direction during the construction work etc..

The sequence for estimation of social cost is figured as below.

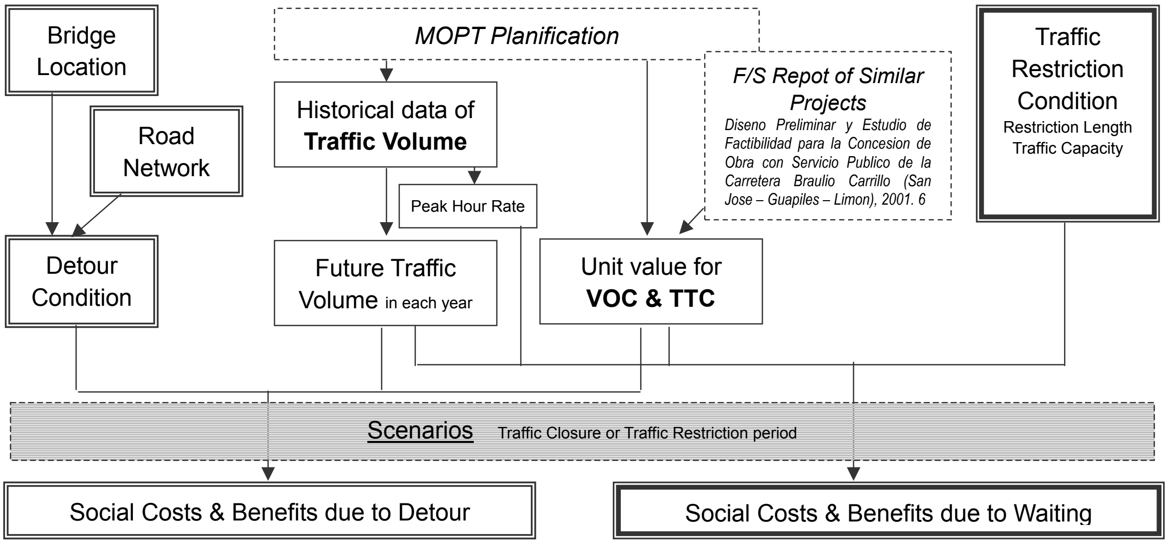


Figure 13.2.1. Estimation Sequence of Social Costs & Benefits

In order to estimate the Social Costs & Benefits due to both detour and waiting, it is necessary to estimate traffic volume in future and to identify the unit value for VOC & TTC. Both of them are already researched by the MOPT planificacion Dept., therefore, after reviewed them, they are applied to this study. Note that the time value for Asset (Goods), is referred by the similar report of feasibility study for road concession projects.

First of all, the future traffic volume should be estimated, and then, the unit value of "Vehicle Operation Cost (VOC)" and "Travel Time Cost (TTC)" should be applied to the deference between the original and detour or waiting case. Followings section will describe the details of each item.

1) Estimation of Traffic Volume

The study team has collected the historical traffic data from the MOPT Planificacion. The estimation method of traffic volume is taken as "Trend Method (External Estimation Method)" instead of Basic Unit Method (Function Model Method) because of the limitation of data accuracy for vehicle registration[1] number and future population & GDP.

MOPT has collected the traffic volume data since 1987 at each station. After identified the station near each bridge, future traffic volume is estimated by the liner function and each category of traffic volume (e.g. Passenger Car, 2-axis truck, 5-axis truck[2]) is divided by the same proportion as the latest traffic volume. The results of estimation formula of traffic volume is shown in the table below. The details are described in Appendix-13.1.

Table 13.2.1. The Results of estimation formula of traffic volume

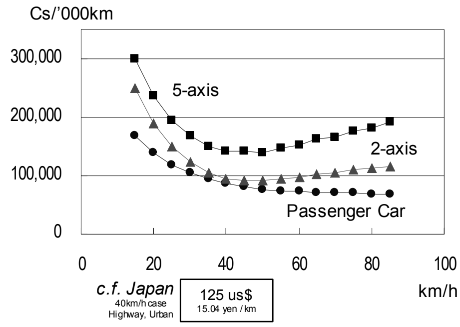
Bridge No.		Route	Estimation Formula of Traffic Volume *Y: Traffic Volume (TPD), X: A.D.,*		Proportion of Vehicle Category %		
					Passenger Car	2 Axis	5 Axis
No 2	Rio Aranjuez	R. 1	*Y = 266.045 X – 525,931*	*(R^2=0.944)*	87.9	4.1	8.0
No 3	Rio Abangares	R. 1	*Y = 314.233 X – 622,921*	*(R^2=0.865)*	87.4	1.9	10.7
No 7	Rio Azufrado	R. 1	*Y = 5.00 X – 8,118*	*(R^2=1.000)*	84.4	3.1	12.5
No12	Rio Puerto Nuevo	R. 2	*Y = 48.379 X – 95,504*	*(R^2=0.790)*	85.1	3.3	11.6
No16	Rio Nuevo	R. 2	*Y = 96.386 X – 190,946*	*(R^2=0.802)*	91.9	2.9	5.2
No17	Rio Chirripo	R. 4	*Y = 218.383 X – 433,253*	*(R^2=0.904)*	89.1	5.1	6.0
No19	Rio Sarapiqui	R. 4	*Y = 139.667 X – 276,441*	*(R^2=1.000)*	91.0	3.6	5.4
No 20	Rio Sucio	R. 32	*Y = 345.338 X – 682,707*	*(R^2=0.902)*	67.7	9.3	23.0
No 26	Rio Chirripo	R. 32	*Y = 374.938 X –743,726*	*(R^2=0.970)*	58.0	9.0	32.0
No 29	Rio Torres	R.218	*Y = 720.313 X –1,405,945*	*(R^2=0.671)*	94.5	3.3	2.2

R^2: Correlation Coefficient Value of Estimation Formula from historical data: R^2=1.00 in Bridge No7 & 19 means that there are only two historical data.
Source: JICA Study Team

2) Unit Value for VOC & TTC

In the MOPT Planification Dept. has researched the unit value for VOC & TTC.

Vehicle operation cost has been estimated in 2004 price followed by HDM-III method. The sturdy team takes the VOC parameter for passenger car, 2-axis truck and 5-axis trailer as figured in right. Note that the comparison between the VOC in Costa Rica and Japan shows the evidence that VOC in Costa Rica is a little higher than in Japan (e.g. VOC (Collones/'000km) for 40km/hr., Costa Rica: 86,278, Japan: 64,625 (125 US$; 15.04 yen/km). See the details in Appendix-13.2



Source: MOPT Planificacion
Figure 13.2.2. VOC Results

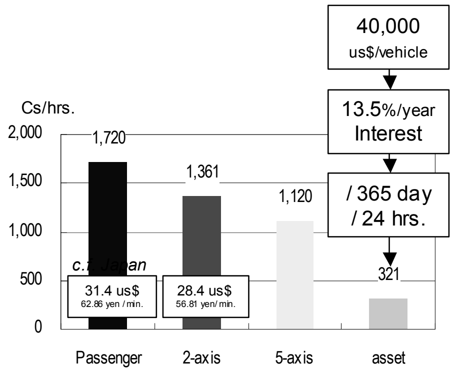
Travel time cost is also researched and described in the feasibility report in Chapter 18 which name is "Diseno Preliminar y Estudio de Factibilidad para la Concesion de Obra con Servicio Publico de la Carretera Braulio Carrillo (San Jose – Guapiles – Limon), 2001. 6".

[1] After data collection of number of vehicle registration since 1987 to 2005, it is found that the data can not be as series because the statistical method has been changed since 2002. Therefore, the Study team decided that the unit method which the future traffic is thought to be estimated by the function with Population, Car ownership, GDP per capita and GDP is difficult to establish.

[2] Vehicle category of traffic volume in MOPT's historical data is classified by i) Passenger Car, ii) Two Axis, iii) Three Axis ,iv) Five Axis and v) Bus. In this study, because of simplified of the task for calculation for VOC & TTC, vehicle category is rearranged as the only three category that are i) Passenger Car included by Bus, ii) Two Axis and iii) Five Axis included by Three Axis.

According this report, TTC for passenger vehicle has been estimated by the interview survey for driver's wage, then it is estimated as 1,924.52 collones/hrs. For the truck and trailer, it has been estimated by the diver's salary as the opportunity cost, then it is estimated as 1,361 for 2-axis truck, 1,120 for 5-axis trailer.

In this study, not only the time value for driver's but also for goods is important to analysis in the case of traffic closure in the international highway especially San Jose – Limon. The study team estimated the time value for goods taking as the opportunity cost if the market value of goods has been saved in advance then the interests has been created. The results of time value of goods is estimated as 321 collones/hrs.



Source: MOPT Planificacion

Figure 13.2.3. TTC Results

Using the researched results of Asset Value of 5- axis (Trailer) = 40,000 us$/vehicle, Goods Asset Value for time is calculated by the interest of saving if goods was sold out earlier.

Note that the comparison between the TTC in Costa Rica and Japan shows the evidence that TTC in Costa Rica is about one tenth of it in Japan (e.g. TTC (Collones/hrs.) for passenger car, Costa Rica: 1,720 vs. Japan: 16,233 (31.4 US$; 62.86 yen/min), for truck, Costa Rica: 1,361 vs. Japan: 14,682 (28.4US$; 56.81 yen/min)).

3) Detour Condition

The detour route is identified by the existing road network for each bridge. For example of Rio Sucio (Route 32), possible detour route is shown in figure right. Each distance and average speed has been calculated by the road inventory data which name is " RED VIAL NACIONAL POR RUTA Y CONDICION, 2005.11" in MOPT Planificacion.

Note only the passenger vehicle and 2-axis truck are possible to use this detour route, but 5-axis trailer is not possible to detour and has to wait until the traffic will open again (Some of them may detour the another route such as R.2 and R.10). The results of each bridge is described in Appendix-13.3

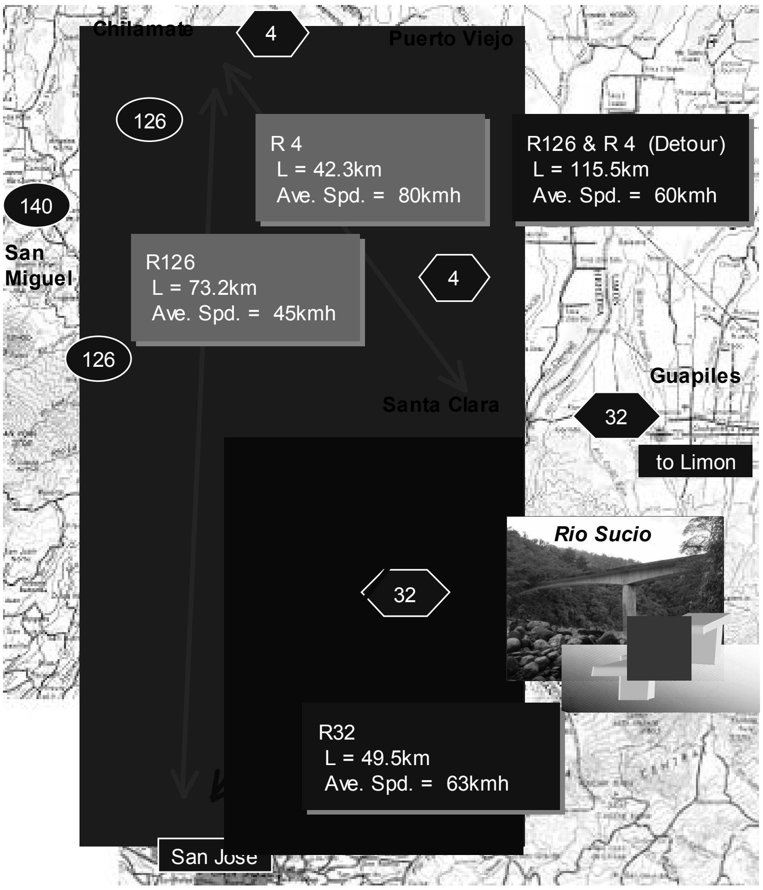
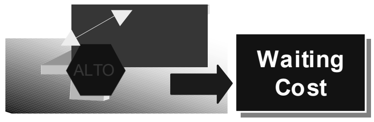


Figure 13.2.4. Detour Route for Rio Sucio (R.32)

4) Waiting Cost

Waiting cost is calculated by the average waiting time, traffic volume and time value in the case of 1-direction traffic restriction during the construction works.



During the traffic restriction for 1-direction, the traffic capacity can be calculated by the equation as follows;

Traffic Capacity for 1-dir. Restriction (veh./hrs.) = - 4 X [Restriction length (m)] + 1,480

Source: Materials for traffic management for in-situ construction on the road, 1997.8, Japan Society of Traffic Engineers

In the case that the actual traffic volume is less than traffic capacity, average waiting time is estimated by the following formula;

$$\textbf{Ave. Waiting Time} = \frac{(\textit{Red Period time})^2}{2 \times \textit{Cycle Period}^* \left(1 - \frac{\textit{Traffic Volume}}{\textit{Traffic Capacity}}\right)}$$

where, the cycle period is assumed as 180 sec. Red period time is assumed as 90 sec.

Note the results of comparison between traffic capacity and peak hour's traffic volume shows that only Rio Sucio (R.32) and Rio Chirripo (R.32) is excess of its traffic capacity. This is caused by the large traffic in peak hour as well as the bridge length is larger (e.g. 200m ~ 450m). If the restriction length is reduced to 100m, it has enough traffic capacity.

13.2.2 Trial Results of Social Costs & Benefits

This section shows the trial results of social loss in the case of "one day traffic closure" and "one day 1-direction traffic restriction" for each bridge using the described above sequence.

1) Social Loss for 1 day Traffic Closure

This is the case of social loss when the traffic is closed in one day in 2007.

For example of Rio Sucio (R.32), traffic volume (TPD) is estimated by the formula, then it is divided by each category (e.g. Passenger Car: 6,948TPD, 2-axis: 966TPD, 5-axis:2,389TPD). According to identified detour route, only the passenger car and 2-axis truck will detour to R.126 to R.4. (e.g. Original condition of R.32: Length = 49.5km, Ave. Speed = 63km/h, Detour condition of R.126 to R.4: Length = 115.5km, Ave. Speed = 60km/h). From the above condition, social loss is estimated 70 million colones and it is about 0.31% of GDP/day. The results of each cost (e.g. VOC, TTC in each vehicle) is shown in the figure below.

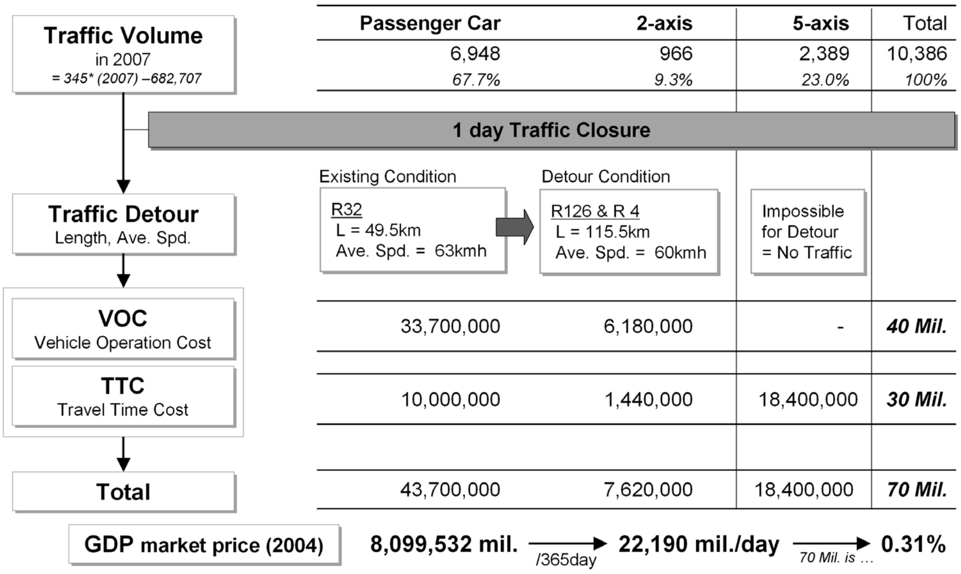


Figure 13.2.5. The Results of Social Loss of 1 day Traffic Closure in Rio Sucio (R.32)

For 10 selected bridges, the social loss has different value according to its detour condition and traffic volume. Note that R32 has the characteristics of mass weight of 5-axis TTC that means of time value of goods. The results is shown in below.

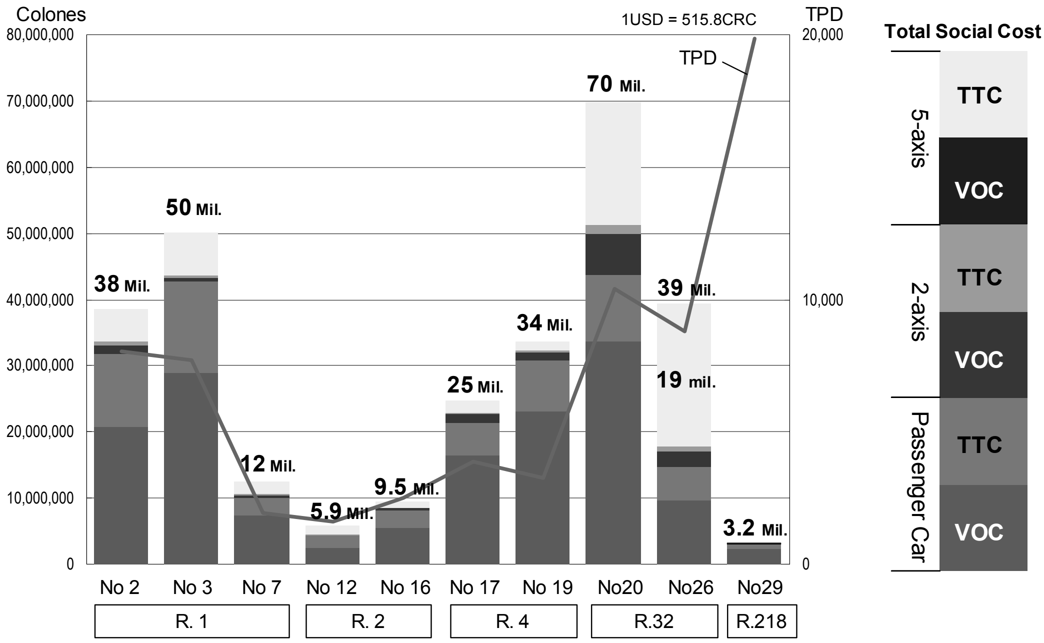


Figure 13.2.6. Social Loss of 1 day Traffic Closure for 10 Bridges

2) Social Loss for 1 day 1-direction Traffic Restriction

This is the case of social loss when the traffic restriction of 1-direction in one day in 2007.

The social loss of 1-dir traffic restriction is much less than of traffic closure. For 10 selected brides, it is about 10,000 to 160,000 colones per day. Note the No29 Rio Toress in R.218 has not been calculated because it is located in metropolitan of San Jose so and is easy to detour the next neighbor route. The figure in right shows the location of Rio Toress and road network.

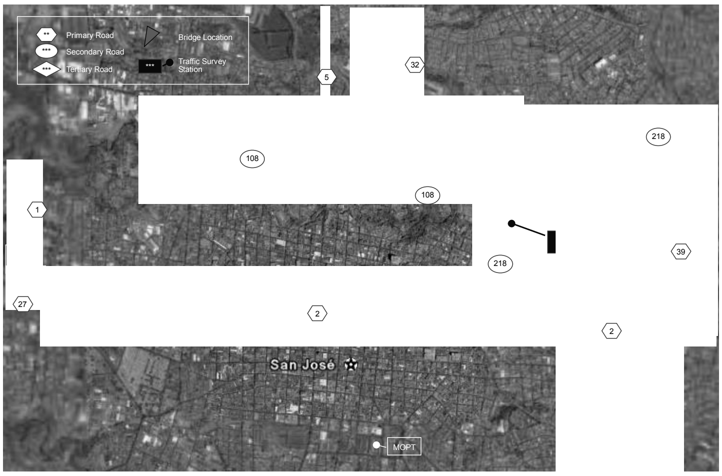


Figure 13.2.7. Location of Rio Toress (R.218)

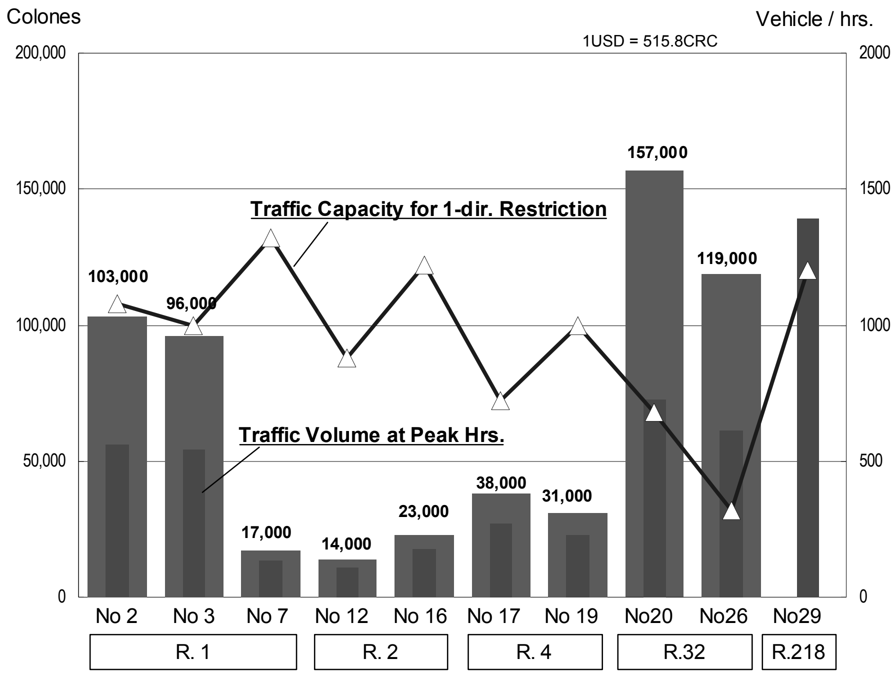


Figure 13.2.8. Social Loss of 1-dir Traffic Restriction in 1 day for 10 Bridges

13.3 Scenario Setting

In the without case, each bridge has their own scenario with unserviceable. The study team decided the each scenario under the engineering judgment with the inspection results of existing condition and age of bridge.

Scenario has the two phase, one is the scenario caused by " Bridge Life", the other is by "Earthquake".

Scenario caused by "Bridge Life" means that the bridge will unusable when a part of the bridge has reached its life corresponding to the existing condition of deterioration. These bridge life is thought to be predictable. On the other hand, scenario caused by "Earthquake" is assumed that the bridge will fall down if an earthquake occurs. Therefore, it is not predictable only has the probability in each year. Both of scenario will affect the traffic such as traffic closure or traffic restriction for 1-direction corresponding to its damaged of bridges. The situation of this scenario shows in the figure below.

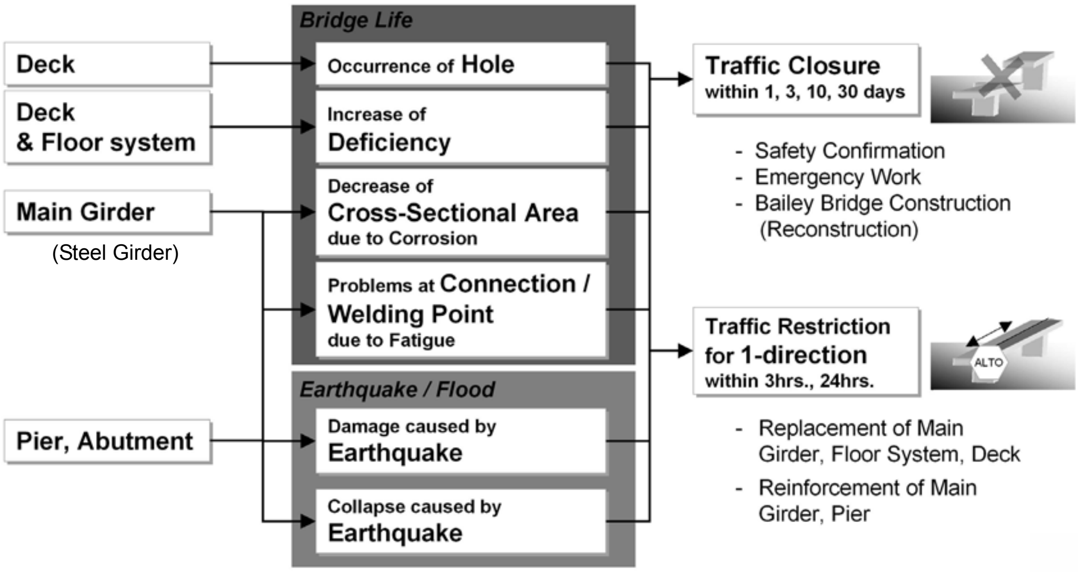


Figure 13.3.1. Considerable Types of Scenario

Each scenario for 10 selected bridges has summarized in Appendix-13.4. In this appendix, it is also indicated that rehabilitation & reinforcement method and maintenance schedule in with case.

Box: Occurrence Probability of Earthquake in Costa Rica

According to historical data of earthquakes in Costa Rica, the Gutenbelg & Richter equation for relationship between the Frequency & Magnitude was established.
The results of occurrence probability with each magnitude level are as follows,
- No12 & No16 Bridge is under most critical situation for an earthquake.
- The results of estimation shows that M6 class will occur within 5 years.

This study takes the M7 class earthquake for the scenario, the earthquake that creates to bridge damage will occur within 20 ~ 50 years at each bridge.

[Gutenbelg & Richter equation] $\text{Log } N = a - b \times M$

N: Probability of Occurrence for each year
a, b: Parameter according to Zone (1 ~ 21)
M: Magnitude Level