CHAPTER 4
TRAFFIC DEMAND FORECAST

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4.1 Results of Traffic Surveys

4.1.1 Outline of Traffic Survey Implementation

The purpose of the traffic survey was to analyze the present road traffic conditions in Bhutan, and to provide a future traffic forecast based on the traffic survey for fundamental data for use in bridge planning and for the feasibility study.

The traffic surveys which were carried out in the Study comprised (1) roadside O-D survey, (2) traffic count survey and (3) travel speed survey.

According to the agreement signed in the Minute of Meeting (M/M) for this Study dated April 22, 1997, the traffic surveys at selected sites were undertaken by traffic survey team of PWD in cooperation with the Royal Bhutan Police. Prior to the field survey, orientation for the traffic survey was held by the Study Team for the counterpart staff in charge of traffic survey. Survey methods were instructed in detail to each field survey team (each Road Maintenance Division concerned) by the counterpart staff by means of "Manual on Traffic Survey" which was prepared by the Study Team in advance.

The methods of each survey are outlined as follows:

(1) Roadside O - D Survey

- Survey Method
  The surveyors stop all vehicles crossing the survey sites for a moment, and interview the driver mainly regarding origin (O), destination (D), trip purpose, etc.
- Survey Site
  In principle, ten (10) sites on the highway crossing the district boundary (see Figure 4.1).
- Survey Time
  7:00 - 19:00 on the continuous three weekdays --- October 7 (Tuesday), 8 (Wednesday) and 9 (Thursday)

(2) Traffic Count Survey

- Survey Method
  The surveyors count vehicles according to type crossing the survey site.

- Survey Site

  Twelve (12) sites (same sites of Roadside O - D Survey, adding Tangmachu and Sunkosh bridge sites) (see Figure 4.1).

- Survey Time

  7:00 - 19:00 on two weekdays --- Oct. 7 (Tuesday) and 9 (Thursday), and 6:00 - 22:00 one weekday --- 8 (Wednesday)

(3) Travel Speed Survey

- Survey Method

  In principle, the surveyors drive two round trips over a fixed section, and record the driving distance and the travel time taken upon crossing the predetermined check point. In case of stopping on the way, they record the reason for stopping and the duration of the stop.

- Survey Road

  National Highway Route No. 1, 2, 3, 4 and 5.

  Although the Indian National Highway (Hasimara- Rangia section) as the alternative route for Bhutanese National Highway Route No. 1(East-West national highway) and the access roads to Bhutanese national highways were intended to be surveyed at the start of the Study, the travel speed survey on these routes was not able to be conducted, owing to security reasons according to the Indian government.

4.1.2 Survey Results

(1) Roadside O-D Survey

The numbers of surveyed vehicles, by survey station and date, which were interviewed by the roadside O-D survey, are shown in Table 4.1.

Table 4.1 Number of Surveyed Vehicles

Survey Date / Survey Station	7 , Oct.		8 , Oct.		9 , Oct.	
	No. of Surveyed Vehicles	No. of Effective Data	No. of Surveyed Vehicles	No. of Effective Data	No. of Surveyed Vehicles	No. of Effective Data
No.01	239	222	252	234	255	254
No.02	55	55	62	64	62	62
No.03	28	28	28	28	28	28
No.04	67	67	39	39	49	48
No.05	21	21	13	13	21	21
No.06	33	33	35	34	34	34
No.07	49	49	46	49	58	58
No.08	68	68	68	67	57	57
No.09	17	16	13	13	18	18
No.10	62	62	53	53	40	40
Total	639	621	609	594	622	620

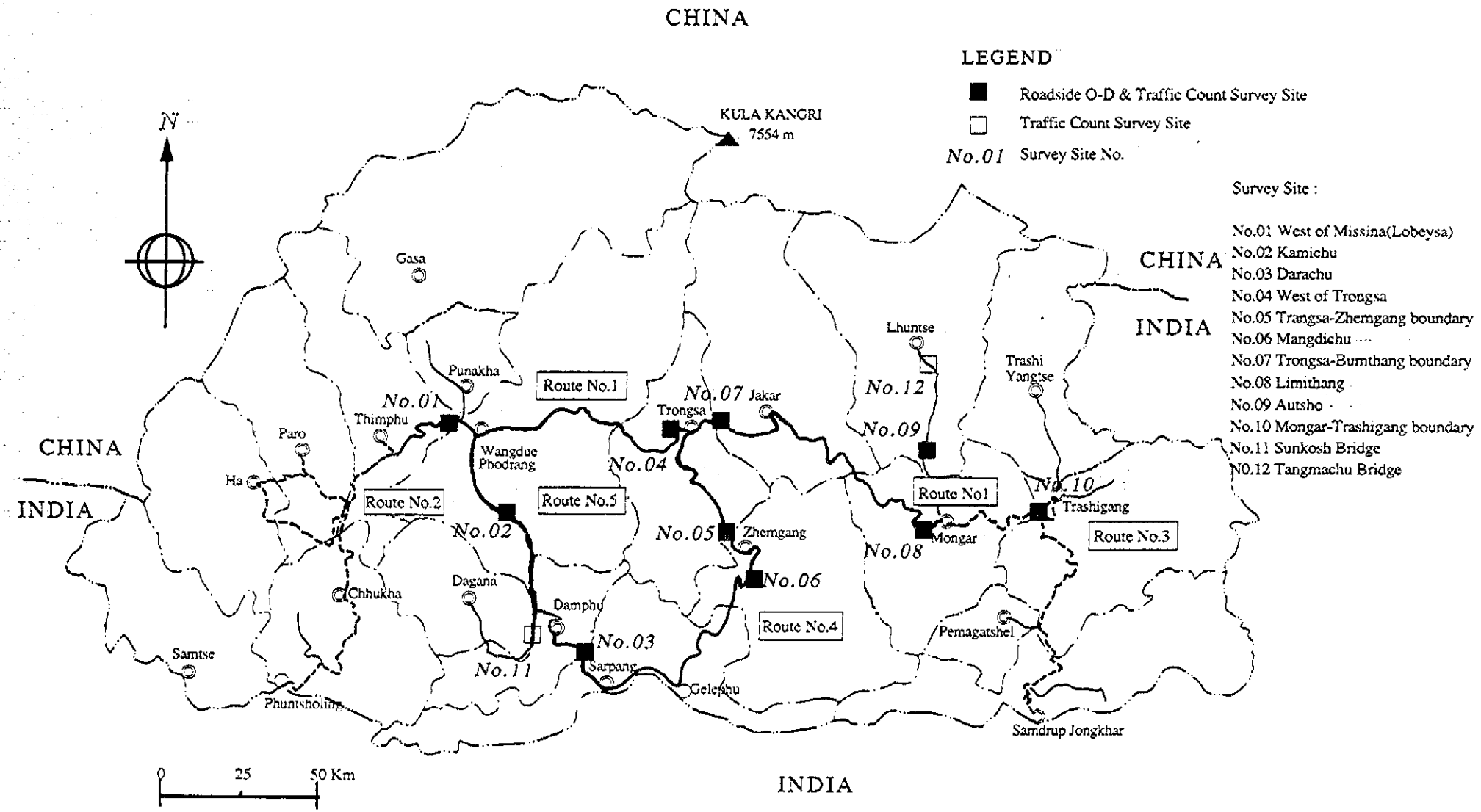


Figure 4.1 Location Map of Traffic Survey Sites

The field survey data from the roadside interview are processed, and present O-D tables are made. The process for establishment of prsent O-D tables by vehicle type is as follows:

- The roadside O-D survey in this Study must attempt to accurately grasp mainly the vehicle traffic flow between districts. Accordingly, the present O-D totalization must be made taking account of the relationship between centers of traffic generation and locations of survey stations along the national highway network. Taking account of accuracy of the surveyed O-D traffic volumes, the zoning for the totalization based on the address(district and block unit) of origins and destinations involved in the roadside O-D survey is established as shown in Table 4.2.
- According to the zoning mentioned above, the 12-hour O-D traffic volumes by survey station, by survey date and by vehicle type are collected and added by zone. The vehicle types are as follows:

  Two wheeler --- Motorcycle/Scooter
  Light vehicle --- Car, Taxi, Pick-up, Light truck
  Heavy vehicle --- Bus, Truck bus, Heavy truck, Special type
- Based on the results of the 12-hour and 16-hour traffic count survey, the expansion factors (16-hour traffic volumes/12-hour traffic volumes) by survey station and by vehicle type are calculated. Then, each O-D table is estimated by 16-hour traffic volume.
- An examination of double check at the mentioned O-D tables; that is checked the duplicate traffic volumes (repeatedly interviewed vehicles) at each survey station, is carried out, and the O-D pair traffic volumes are adjusted. Then the whole country O-D tables by survey date during three days, which integrate the O-D tables by survey station and by vehicle type, are established.
- O-D tables by vehicle type for the whole country are established, based on the calculation of the average daily O-D pain traffic volumes.

Table 4.2 Zone Code for Totalization

Zone Code	District
A	Chhukha, Ha, Paro, Samtse, Thimphu
B	Gasa, Punakha, Wangdue Phodrang
C	Bumthang
D	Dagana, Tsirang
E	Lhuentse
F	Mongar
G	Sarpang
H	Trongsa
I	Zhemgang
J	Pemagathel, Samdrup Jongkhar, Trashigang, Yangtse
9300	to/from India via Sarpang/Gelephu
9400	to/from India via Samdrup Jongkhar

O-D tables for the whole country which are made in accordance with the above process are shown in Table 4.3. Figure 4.2 is the desire line based on the all-vehicle O-D table.

From Figure 4.2, the present pattern of intercity trip distribution in Bhutan shows that Thimphu is the center of trip distribution. Moreover, the intercity traffic demand along National Highway Route No. 1 as East-West highway becomes high comparatively.

(2) Traffic Count Survey

Figure 4.3 shows the traffic count survey results.

(3) Travel Speed Survey

The travel speed survey results are shown in Figure 4.4. From the survey results, the vehicle running speeds on highway sections with winding and horizontal alignment with many hairpin bends are naturally low, e.g., Nobding-Trongsa section which includes Pelela pass, Trongsa-Yutongla section and Ura-Thumsingla section(include Thumsingla pass) on National Highway Route No. 1, Lamthey-Zhemgang section and Tingtibi-Surey section on National Highway Route No. 4.

The running times required between major towns from survey results are as follows:

Route No. 1	Semtokha-Trongsa (210 Km)	6.3 hours
	Trongsa- Trashigang (368 Km)	11.1 hours
	Semtokha-Trashigang (578 Km)	17.4 hours
Route No. 2	Thimphu-Phuntsholing (180 Km)	4.9 hours
Route No. 3	Trashigang-Samdrup Jonkhar (183 Km)	5.1 hours
Route No. 4	Trongsa-Gelephu (258 Km)	7.9 hours
Route No. 5	Wangdue Phodrang-Sarpang (164 Km)	4.8 hours

Table 4.3 Present O-D Table by Vehicle Type

(Two Wheelers)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	42	2	3	1	0	0	2	1	0	0	0	51
B		-	2	5	0	0	2	0	1	0	0	0	52
C			-	0	0	2	0	3	2	0	0	0	11
D				-	0	0	0	0	0	0	0	0	8
E					-	5	0	0	0	1	0	0	7
F						-	0	1	0	6	0	0	14
G							-	1	2	0	0	0	5
H								-	3	0	0	0	10
I									-	0	0	0	9
J										-	0	0	7
9300											-	0	0
9400												-	0
												Total	174

(Light Vehicles)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	100	21	18	1	5	10	9	4	9	4	2	183
B		-	6	19	0	0	1	4	0	1	0	0	131
C			-	0	1	2	2	7	3	2	0	0	44
D				-	0	0	6	0	0	0	0	0	43
E					-	3	0	1	0	2	0	0	8
F						-	0	2	1	28	0	0	41
G							-	2	2	0	0	0	23
H								-	5	2	0	0	32
I									-	0	0	0	15
J										-	0	0	44
9300											-	0	4
9400												-	2
												Total	570

(Heavy Vehicles)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	63	8	4	0	4	6	8	4	2	0	0	99
B		-	3	2	0	0	1	1	0	0	1	0	71
C			-	0	0	1	2	2	1	0	0	0	17
D				-	0	0	6	0	0	0	0	0	12
E					-	4	0	0	0	2	0	0	6
F						-	0	1	0	20	0	3	33
G							-	3	7	0	0	0	25
H								-	1	2	1	1	20
I									-	0	0	0	13
J										-	0	0	26
9300											-	0	2
9400												-	4
												Total	328

(All Vehicles)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	205	31	25	2	9	16	19	9	11	4	2	333
B		-	11	26	0	0	4	5	1	1	1	0	254
C			-	0	1	5	4	12	6	2	0	0	72
D				-	0	0	12	0	0	0	0	0	63
E					-	12	0	1	0	5	0	0	21
F						-	0	4	1	54	0	3	88
G							-	6	11	0	0	0	53
H								-	9	4	1	1	62
I									-	0	0	0	37
J										-	0	0	77
9300											-	0	6
9400												-	6
												Total	1072

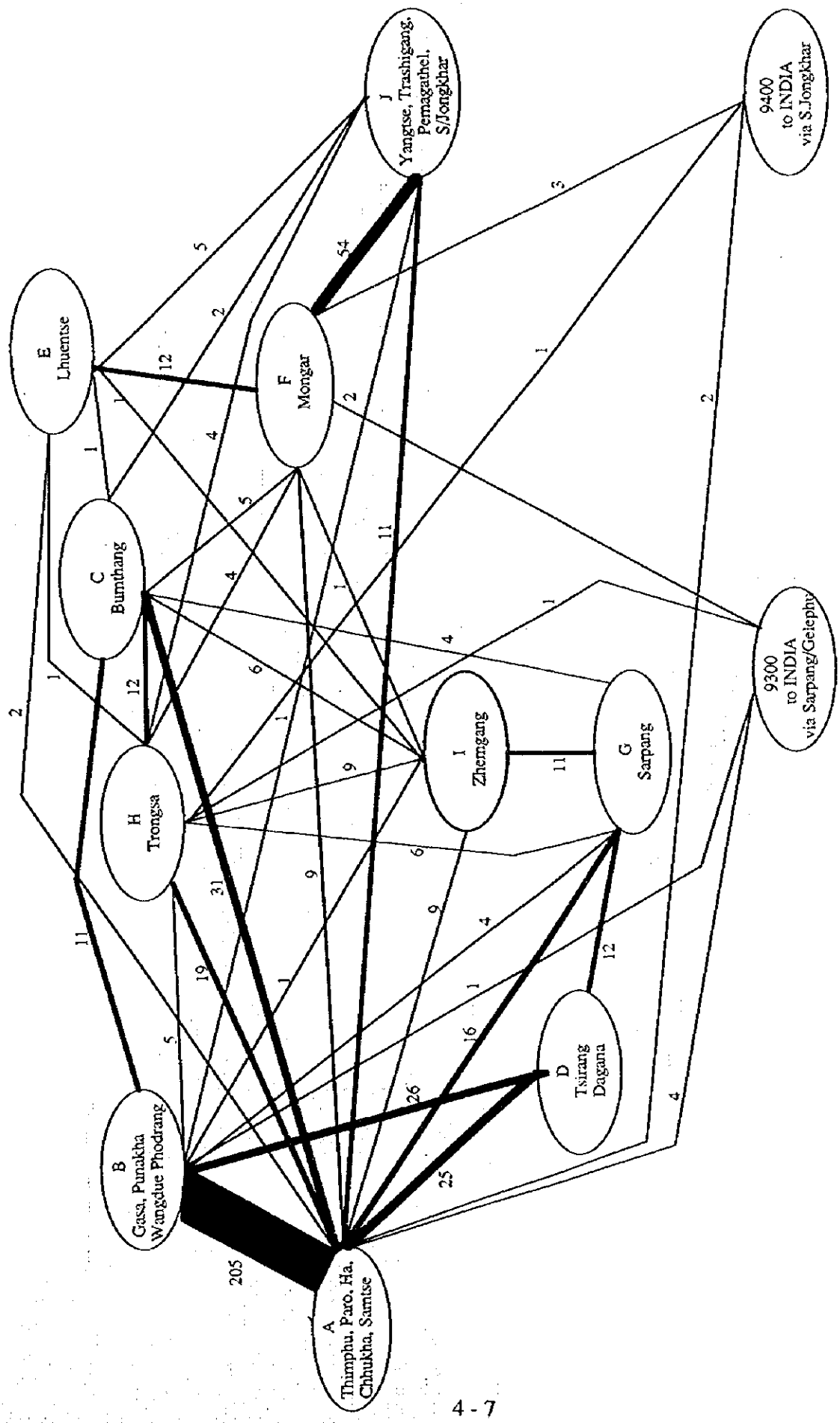


Figure 4.2 Desire Line Chart in 1997

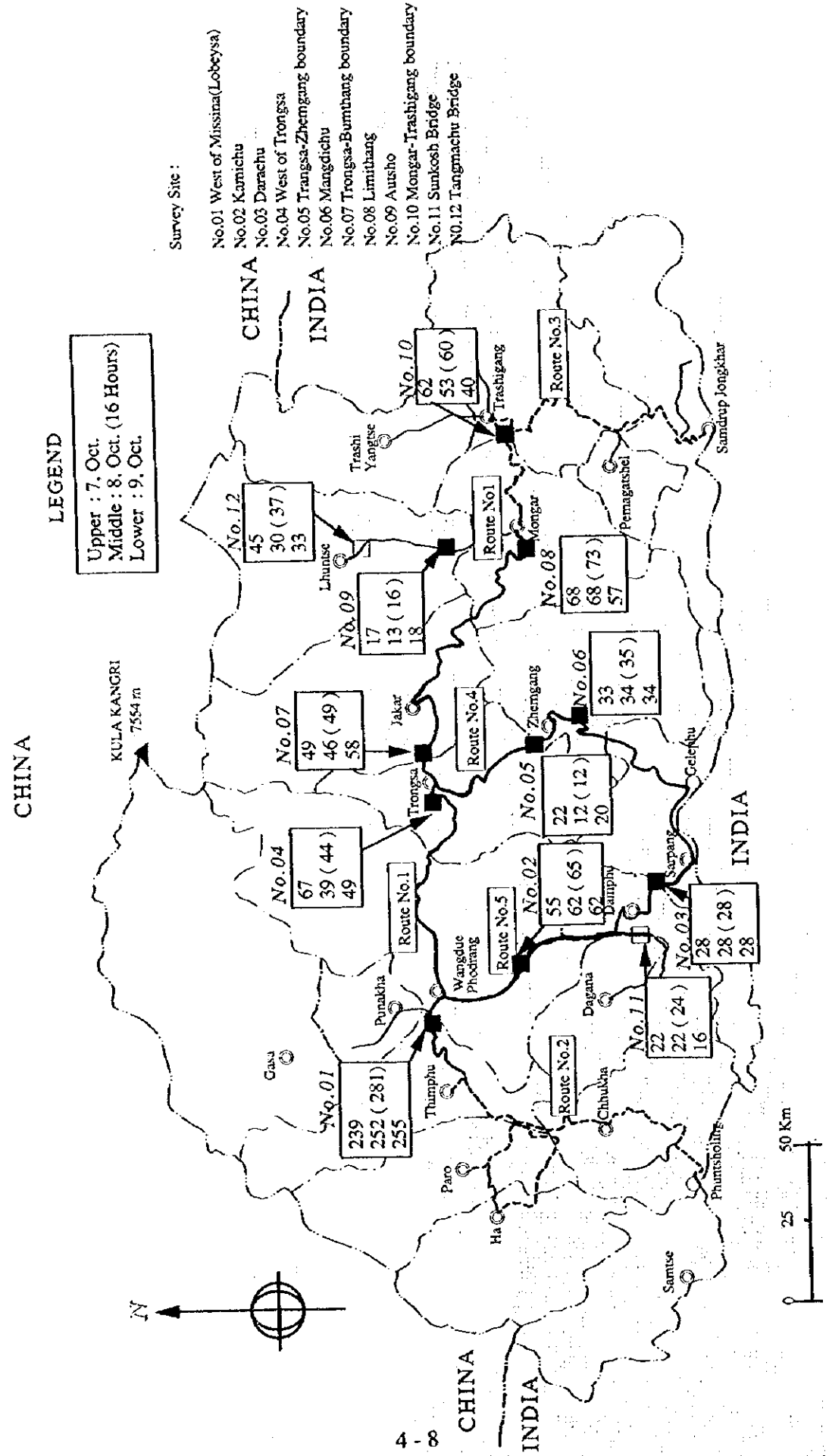


Figure 4.3 Traffic Count Survey Results

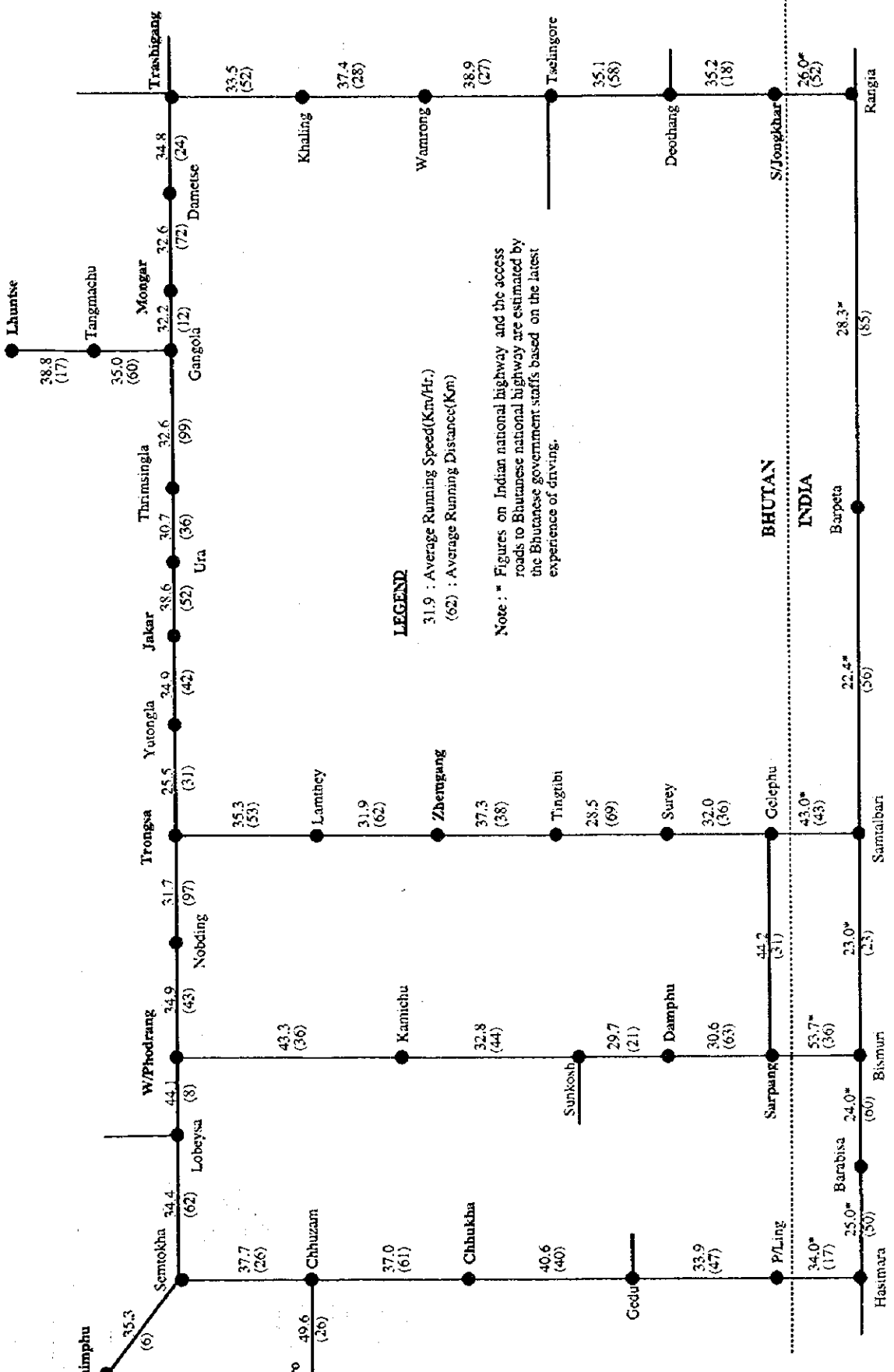


Figure 4.4 Running Speed by Road Section (Sep.-Oct. 1997)

4.2 General Outline of Traffic Forecast

A method for traffic demand forecast will generally be examined through the analysis of the relations between present Origin-Destination (O-D) table and current socioeconomic data by zone(area). The process is as follows:

(Step 1)
- to make the present models, i.e., trip generation model, trip distribution model and trip assignment model, through analysis of relations between traffic volumes and socioeconomic figures by zone.

(Step 2)
- to estimate future socioeconomic data by zone based on the future socioeconomic framework mentioned in section 2.2.
- to forecast future trip generation by zone by substituting future socioeconomic figures by zone to trip generation model.

(Step 3)
- to forecast future trip distribution (future O-D table).

(Step 4)
- to assign future traffic volumes on the road network.

The process for traffic forecast mentioned above is shown in Figure 4.5.

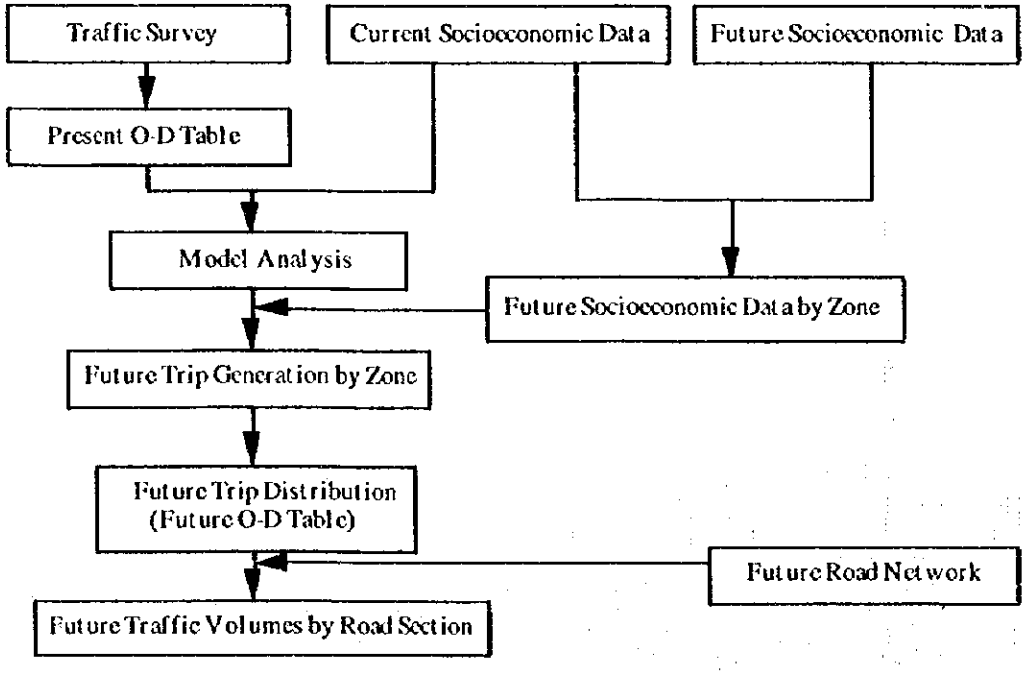


Figure 4.5 Flowchart of Traffic Forecast

4.3 Future Road Network

4.3.1 Existing Future Plan for Road Sector

Bhutan's steep and fragile terrain, a lack of trained and skilled manpower, and budgetary limitations combine to present a serious challenge to the construction and maintenance of road.

Taking account of the present situations in the road sector, the objectives and programs for road development are described as follows in the document of the 8FYP:

(1) Objectives

- To develop a sustainable and regionally balanced road network that is safe, convenient and economical to use;
- To preserve the past capital investment in road, reduce cost of vehicle operation and the travel time of road users and develop road construction and maintenance (resurfacing) capabilities in the private sector.

(2) Programs

For programs in road development, please refer to the Section 3.2 (Road Development Plan).

4.3.2 Future Road Network

According to the road development plan mentioned above, it can be seen that the existing trunk road network is not changed greatly by new road construction programs, since the programs aim mainly to improve accessibility of rural communities through the expansion of district and feeder road network.

Accordingly, the future trunk road network in this Study is fundamentally the same as shown in Figure 2.5.

4.4 Future O-D Matrices

4.4.1 Model Analysis

As mentioned above in Section 3.2 (Step 1), the making of a present model is attempted through analysis of relations between the present traffic volumes and socioeconomic figures by zone.

(1) Trip generation model

Trip generation models are analyzed based on the relation between the current trip generation by zone and the total and urban population by zone, as population data was the only zonal socioeconomic data that could be obtained. The results of trip generation model analysis are as follows:

- The correlations between the current trip generation by zone and the total and urban population by zone are low, shown in Figure 4.6.
- The making of trip generation models is difficult due to the large dispersion of data.

(2) Trip distribution model

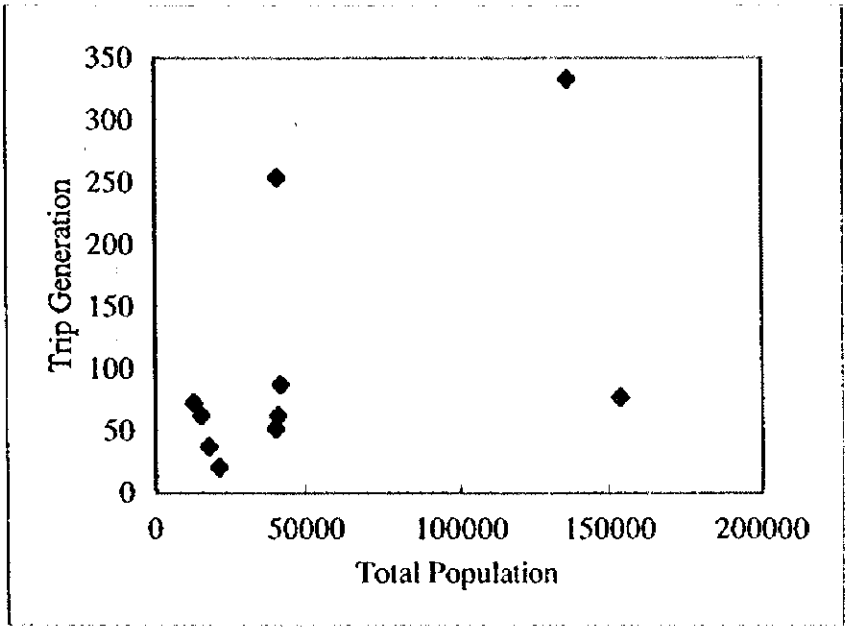
As development plans have contributed to the generation of large traffic volumes, and due to the fact that the road development plans related to major changes in road network conditions are unknown, a present pattern method as trip distribution model is adopted in principle.

4.4.2 Future O-D Matrix Forecast

Taking account the results of model analysis into consideration, the future O-D matrix forecasts in this Study are carried out by the following process:

- On account of the limited information on socioeconomic data by zone, only population data can be used for a index of growth rate estimates of traffic volumes. The future population by zone in the year 2000, 2005, 2010, 2015 and 2020 were forecsated by the methods of examination which reflected the changing rates of composition ratio of population by zone between the 1980 census data and the 1995 LUPP Dzongkhag data (see Table 4.4). For example, the formulas for estimates of population by district in 2000 and 2005 are as follows:

(Trip Generation and Total Population)



(Trip Generation and Urban Popuration)

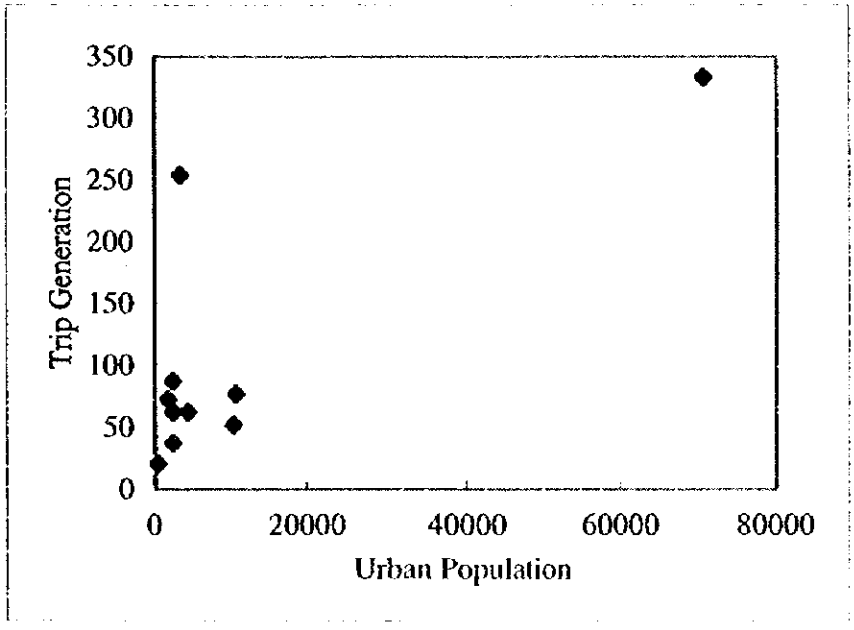


Figure 4.6 Correlation between Trip Generation and Population

(2000 year)

$$POP_{2000}\,i = POP_{2000} \times (B_{2000}\,i \;/\; \Sigma B_{2000}\,i)$$

$$B_{2000}\,i = POP_{1995}\,i \times POP_{2000} / POP_{1995} \times A\,i^{(2000-1995)}$$

$$A\,i = \{(POP_{1995}\,i / \Sigma POP_{1995}\,i) / (POP_{1980}\,i / \Sigma POP_{1980}\,i)\}^{1/(1995-1980)}$$

(2005 year)

$$POP_{2005}\,i = POP_{2005} \times (B_{2005}\,i \;/\; \Sigma B_{2005}\,i)$$

$$B_{2005}\,i = POP_{1995}\,i \times POP_{2005} / POP_{1995} \times A\,i^{(2005-2000)}$$

$$A\,i = \{(POP_{2000}\,i / \Sigma POP_{2000}\,i) / (POP_{1995}\,i / \Sigma POP_{1995}\,i)\}^{1/(2000-1995)}$$

where, $POP_{1980}\,i$, $POP_{1995}\,i$, $POP_{2000}\,i$ and $POP_{2005}\,i$: Population by district in 1980, 1995, 2000 & 2005

POP_{1995}, POP_{2000} and POP_{2005} : Total population in 1995, 2000 & 2005

- The growth rates of trip generation by zone are calculated by geometrical means between population growth rates by zone and vehicle ownership growth rates as mentioned above in Section 2.2 (Future Socioeconomic Framework). The calculation fomula is as follows:

$$TRi = \sqrt{PRi \times VR}$$

where, TRi : Growth rate of trip generation by zone
PRi : Growth rate of population by zone
VR : Growth rate of vehicle ownership

- Future O-D matrices are estimated by multiplying the elements of the present O-D matrix by geometrical means of trip generation growth rates by zone. The calculation formula is as follows:

$$FOD\,ij = POD\,ij \times \sqrt{TR\,i \times TR\,j}$$

where, FOD ij : Future O-D pair volume between i zone and j zone
POD ij : Present O-D pair volume between i zone and j zone
TRi and TRj : Trip generation growth rate of zone i and zone j

Table 4.4 Future Population by Zone

Zone Code	Dzongkhag	Estimated Population						Growth Rate				
		1996	2000	2005	2010	2015	2020	2000/1996	2005/1996	2010/1996	2015/1996	2020/1996
A	Thimphu	48,293	57,400	74,500	89,400	105,200	122,000	1.19	1.54	1.85	2.18	2.53
	Chhukha	59,917	66,700	77,000	88,300	98,200	107,300	1.11	1.29	1.47	1.64	1.79
	Ha	8,489	8,800	10,100	10,500	10,700	10,800	1.04	1.19	1.24	1.26	1.27
	Paro	19,574	20,200	23,300	24,100	24,500	24,600	1.03	1.19	1.23	1.25	1.26
	Samtse	77,564	83,500	96,700	105,800	113,300	119,600	1.08	1.25	1.36	1.46	1.54
	Sub-total	213,837	236,600	281,600	318,100	351,900	384,300	1.11	1.32	1.49	1.65	1.80
B	Punakha	16,199	17,400	20,100	22,000	23,500	24,700	1.07	1.24	1.36	1.45	1.52
	Gasa	3,008	3,200	3,700	4,100	4,400	4,700	1.06	1.23	1.36	1.46	1.56
	Wangdue Phodrang	24,402	25,500	29,500	31,000	32,000	32,600	1.04	1.21	1.27	1.31	1.34
	Sub-total	43,610	46,100	53,300	57,100	59,900	62,000	1.06	1.22	1.31	1.37	1.42
C	Bumthang	12,675	13,500	15,600	16,700	17,600	18,300	1.07	1.23	1.32	1.39	1.44
D	Tsirang	19,645	20,200	23,300	24,000	24,300	24,300	1.03	1.19	1.22	1.24	1.24
	Dagana	20,944	24,900	28,800	36,300	43,900	51,700	1.19	1.38	1.73	2.10	2.47
	Sub-total	40,589	45,100	52,100	60,300	68,200	76,000	1.11	1.28	1.49	1.68	1.87
E	Lhuentse	21,144	23,000	26,500	29,400	31,800	33,800	1.09	1.25	1.39	1.50	1.60
F	Mongar	41,453	45,200	52,200	58,300	63,400	67,800	1.09	1.26	1.41	1.53	1.64
G	Sarpang	39,647	41,400	47,800	50,100	51,700	52,700	1.04	1.21	1.26	1.30	1.33
H	Trongsa	15,563	16,600	19,200	20,800	22,000	22,900	1.07	1.23	1.34	1.41	1.47
I	Zhemgang	17,925	17,500	20,200	19,200	18,200	17,200	0.98	1.13	1.07	1.02	0.96
J	Pemagatshel	20,169	21,900	25,300	28,100	30,400	32,400	1.09	1.25	1.39	1.51	1.61
	Samdrup Jongkhar	43,178	47,600	54,900	62,100	68,300	73,800	1.10	1.27	1.44	1.58	1.71
	Trashigang	69,310	73,400	84,800	90,500	95,000	98,200	1.06	1.22	1.31	1.37	1.42
	Yangtse	20,900	22,100	25,500	27,300	28,600	29,600	1.06	1.22	1.31	1.37	1.42
	Sub-total	153,557	165,000	190,500	208,000	222,300	234,000	1.07	1.24	1.35	1.45	1.52
	Total	600,000	650,000	759,000	838,000	907,000	969,000	1.08	1.27	1.40	1.51	1.62

Source : The Study Team

Note : Total Population are from the 8FYP document.

The future O-D matrices for 2020 estimated according to the above process are shown in Table 4.5. Figure 4.7 shows the desire line chart for 2020.

Table 4.5 Future O-D Matrices in 2020

(Two Wheelers)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	144	7	11	4	0	0	7	3	0	0	0	176
B		-	6	17	0	0	6	0	3	0	0	0	176
C			-	0	0	7	0	10	6	0	0	0	36
D				-	0	0	0	0	0	0	0	0	28
E					-	17	0	0	0	3	0	0	24
F						-	0	3	0	20	0	0	47
G							-	3	6	0	0	0	15
H								-	9	0	0	0	32
I									-	0	0	0	27
J										-	0	0	23
9300											-	0	0
9400												-	0
												Total	584

(Light Vehicles)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	386	81	75	4	20	38	35	14	35	17	8	713
B		-	22	73	0	0	4	14	0	4	0	0	503
C			-	0	4	7	7	25	10	7	0	0	163
D				-	0	0	23	0	0	0	0	0	171
E					-	11	0	4	0	7	0	0	30
F						-	0	7	3	106	0	0	154
G							-	7	6	0	0	0	85
H								-	16	7	0	0	115
I									-	0	0	0	49
J										-	0	0	166
9300											-	0	17
9400												-	8
												Total	2174

(Heavy Vehicles)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	259	33	18	0	17	24	33	15	8	0	0	407
B		-	11	8	0	0	4	4	0	0	4	0	290
C			-	0	0	4	8	8	3	0	0	0	67
D				-	0	0	24	0	0	0	0	0	50
E					-	16	0	0	0	8	0	0	24
F						-	0	4	0	80	0	12	133
G							-	11	24	0	0	0	95
H								-	3	8	4	4	79
I									-	0	0	0	45
J										-	0	0	104
9300											-	0	8
9400												-	16
												Total	1318

(All Vehicles)

	A	B	C	D	E	F	G	H	I	J	9300	9400	Tripends
A	-	789	121	104	8	37	62	75	32	43	17	8	1296
B		-	39	98	0	0	14	18	3	4	4	0	969
C			-	0	4	18	15	43	19	7	0	0	266
D				-	0	0	47	0	0	0	0	0	249
E					-	44	0	4	0	18	0	0	78
F						-	0	14	3	206	0	12	334
G							-	21	36	0	0	0	195
H								-	28	15	4	4	226
I									-	0	0	0	121
J										-	0	0	293
9300											-	0	25
9400												-	24
												Total	4076

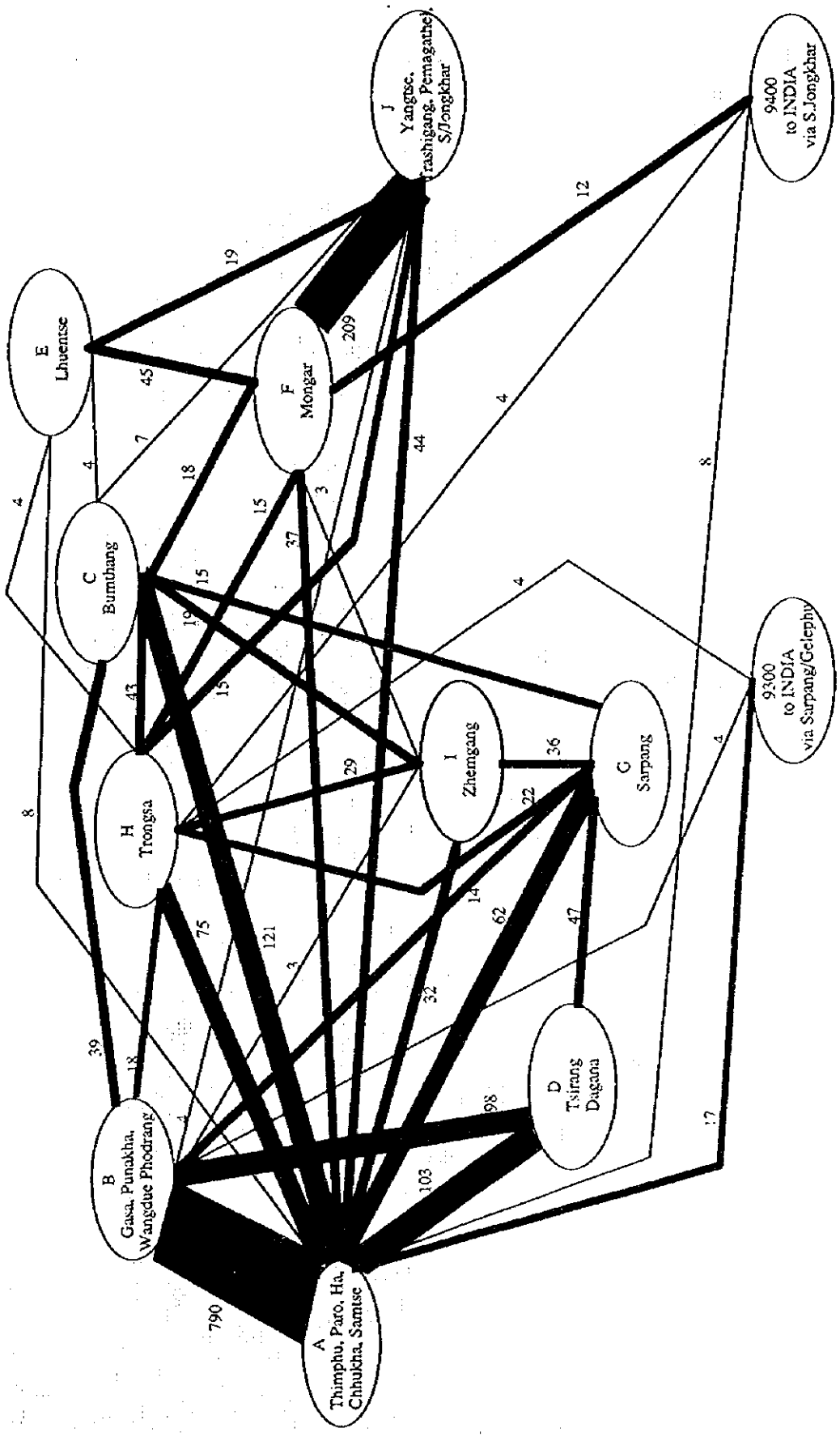


Figure 4.7 Desire Line Chart in 2020

4.5 Future Traffic Demand on National Highway Sections

Future traffic volumes on the national highway sections are estimated by traffic assignment calculation, which is a procedure of assigning future O-D matrix to a highway network. This procedure requires, as input, the complete description of the future highway network and future O-D matrix.

The assignment method applied here is what is called "all-or-nothing method" in which all the vehicles for a certain O-D pair are assigned the shortest route among the possible route alternatives.

The reason why this method is applied come from following characteristics in highway traffic in the Study area:

- Traffic volumes on most of the highways in the Study area are far below the level of capacity.
- The road network in the Study area is rather simple due to low density of roads in this country.

Moreover, the preconditions for the traffic assignment calculation are as follows:

- Future highway network for traffic assignment is composed of the existing highway network in Bhutan and a part of the Indian highway which is the alternative route for the east-west highway (Route No.1) (refer to Figure 4.4).
- Running speed levels by vehicle type are the sole parameter in the case of assignment of all-or-nothing mehtod. Vehicle running speeds by network section obtained by the Travel Speed Survey are applied for this purpose (see Figure 4.4).

Figure 4.8 shows the results of traffic assignment for 2020. It is necessary to note that the assigned traffic volumes are not included the traffic volumes moving within the zones, as the O-D matrixes are composed only of those between zones.

The assigned traffic volumes passing each Project Bridge according to traffic assignment in 2020 are shown below:

No. 1	Kurizampa	169	
No. 2	Chamkar Zam	169	
No. 3	Bjee	388	
No. 4	Wachy Zam	388	
No. 5	Mangdichu	76	
No. 6	Wangdigang	90	
No. 8	Ishigangchu	90	
No.10	Lawakha	299	
No.16	Wakleytar	299	
No.17	Mechikhola	299	
No.21	Tangmachu	78	
No.22	Sunkosh	117	(multiplied traffic count data by growth rate of traffic generation for Dagana)

As mentioned above, the real traffic volumes passing each bridge, especially Chamkar Zam and Bjee bridge nearby urban area, will be more than these traffic volumes assigned, since intra city traffic will be added.

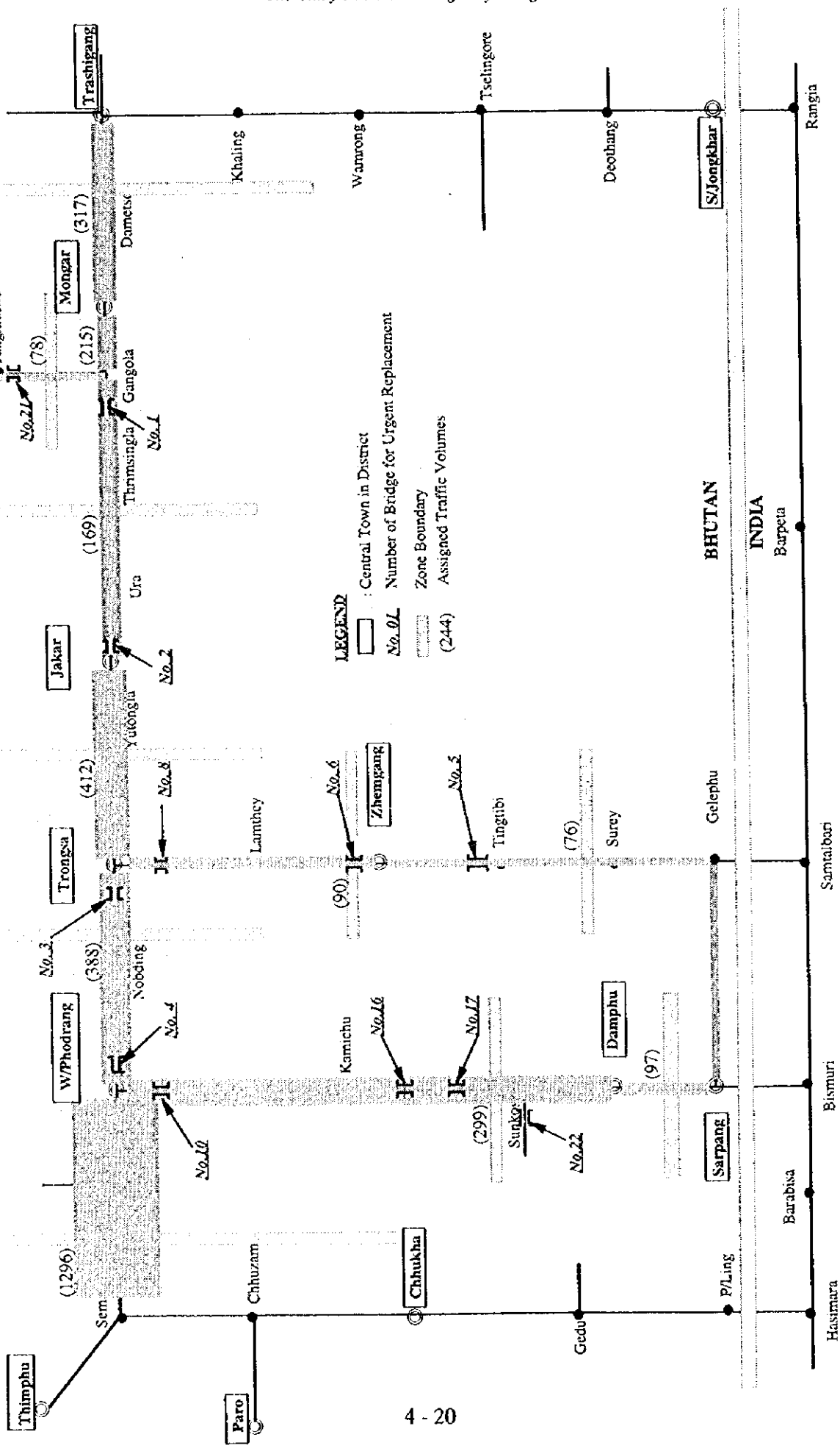


Figure 4.8 Assigned Traffic Volumes in 2020

CHAPTER 5

SELECTION OF BRIDGES FOR THE FEASIBILITY STUDY

CHAPTER 5 SELECTION OF BRIDGES FOR THE FEASIBILITY STUDY

5.1 Preliminary Identification of Bridges

5.1.1 Present Condition of Bridges

In order to study the present condition of 22 bridges, preliminary and detailed bridge field surveys were conducted in the 1st Field Survey Stage.

(1) Preliminary Bridge Survey

The preliminary bridge survey was carried out for 22 bridges to verify their locations, accessibility and environmental aspects. The major purpose of this survey was to investigate the present condition of bridges.

Also the results of the preliminary bridge survey was used to obtain information on existing bridge maintenance and management systems, and work performed by PWD.

At the same time the Initial Environment Evaluation (IEE) was carried out for 22 bridges to obtain current environmental situation of the bridge sites and surrounding areas.

(2) Detailed Bridge Survey

After the results of the preliminary bridge survey were analyzed, the detailed bridge survey was carried out to clarify the details of the present conditions of the 22 bridges.

Outlines of twenty two bridges are shown in Appendix-A.

(3) Bridge Inventory and Inspection Forms

The following papers were prepared for all 22 bridges, as reference materials for the selection of bridges urgently requiring replacement from the engineering point of view.

- Bridge Inventory
- Bridge Inspection Form
- Photographs

These documents are shown in Appendix-C.

A list of 22 bridges is shown in Table 5.1

(4) Detailed Bridge Site Survey in Winter Season

In order to obtain the site conditions and transportation conditions detailed bridge survey was conducted in February 1998. The photographs are shown in Appendix-B.

Table 5.1 List of Bridges

Bridg No.	Bridge Name	HW.Route No.	River Name	Dzongkhag	Type of Bridge	Bridge Length (m)	Loading Capacity (t)	Completion (year)	Age
1	Kurizampa	1	Kurichu	Mongar	Bailey TSR	42.7	5	1971	26
2	Chamkar Zam	1	Chamkarchu	Bumthang	Bailey DS	33.7	5	1973	24
3	Bjee	1	Mangdichu	Trongsa	Bailey TSR	42.7	9	1969	28
4	Wachy Zam	1	Dangchu	Wangdue	Bailey DSR	33.7	18	1969	28
5	Mangdichu	4	Mangdichu	Zhemgang	Bailey Suspension	97.4	4	1965	32
6	Wangdigang	4	Wangdigangchu	Zhemgang	Bailey DS	30.5	15	1969	28
7	Panjurmani	4	Kartigangchu	Trongsa	Steel Beam (*)	9.0	7	1995	2
8	Ishigangchu	4	Ishigangchu	Trongsa	Bailey DS	36.6	15	1992	5
9	Hesothangkha	5	Hesothangkhachu	Wangdue	Bailey SS	9.2	18	1985	12
10	Lawakha	5	Lawakhachu	Wangdue	Bailey DSR	30.5	18	1988	9
11	Basochu	5	Basochu	Wangdue	Bailey SSR	18.3	15	1985	12
12	Rurichu	5	Rurichu	Wangdue	Bailey SS	15.3	18	1987	10
13	Baychu	5	Baychu	Wangdue	Bailey SS	15.3	17	1985	12
14	Kamichu	5	Kamichu	Wangdue	Bailey SS	18.3	15	1986	11
15	Narachu	5	Narachu	Daga	Bailey DS	30.5	24	1991	6
16	Wakleytar	5	Sunkosh	Tsirang	Bailey Suspension	73.2	12	1987	10
17	Mechikhola	5	Mechikhola	Tsirang	Timber Truss	18.0	8	1990	7
18	Burichu	5	Burichu	Tsirang	Bailey DS	27.5	18	1985	12
19	Chanchey	5	Chancheychu	Tsirang	Bailey TS	39.7	18	1986	11
20	Loringkhola	5	Loringkhola	Sarpang	Bailey DDR	48.8	18	1992	5
21	Tangmachu	Mon./Lhue	Kurichu	Lhuentse	Bailey Suspension	85.2	12	1982	15
22	Sunkosh	Tsir./Sun.	Sunkosh	Daga	Bailey Suspension	85.2	12	1982	15

Mon./Lhue : Mongar/Lhuentse
Tsir./Sun. : Tsirang/Sunkosh

* : Temporary Bridge
Loading Capacity : PWD's estimated load and limited load capacity

5.1.2 Criteria of Preliminary Selection

The following factors have been considered as criteria for preliminary selection of bridges deemed to be in greatest need of replacement.

- Present capacity of bridges to the live load
- Age of bridges
- Evaluation of Bridge Damage Rating
- Relation between sag and span length
- Socioeconomic conditions around the bridge sites

(1) Present capacity of bridges to the live load

PWD maintains 22 bridges and specifies their present capacity. All bridges except Bridge Nos.7 and 17 are Bailey bridges, which are commonly used as temporary structures.
The present loading capacity is shown in Table 5.1. Bridges with limited load capacity of less than 15 tons are recommended for replacement as soon as possible, since the average weight of vehicles passing national highways at present is 15 tons or more.

(2) Age of bridges

The design life of Bailey bridges is usually said to be 15 to 20 years. Years of completion and ages of bridges are shown in Table 5.1.
In light of this, since Bridges Nos. 1 to 6 were constructed 24 or more years ago, it is recommended that these bridges should be replaced as soon as possible.

(3) Evaluation of Bridge Damage Rating

To clarify the state of deterioration of structures, the following system was employed in rating the amount of bridge damage.

Rate

Rate	Rate Criteria
1	No damage found as result of inspection
2	Damage found and requires routine maintenance and inspection
3	Damage is critical and requires a detailed inspection to determine necessity of rehabilitation work.
4	Damage is highly critical and urgently requires rehabilitation work, load limitation or replacement.

Weighted Factor

Damage rating for each bridge was carried out by evaluating the damage of each structural part. A **Weighted Factor** was selected for each structural part, based on its importance and difficulty of partial replacement.

The Weighted Factor for each structural part is determined as follows:

	Structural Part	Weighted Factor
Superstructure	Main beam and deck frame	1.0
	Tower, cables, anchorage and hanger ropes	1.0
	Pavement, timber slab and curb	0.5
Substructure	Abutment	1.0
	Wing wall	0.5
	River bank	0.5
	Approach	0.5
Bearing	Bearing	0.8

The Damage Rating is calculated by multiplying the **Rate** by the **Weighted Factor** of each part, and the greatest value among the three (superstructure, substructure, bearing) is chosen as the Bridge Damage Rating.
Results of damage rating for the 22 bridges are shown in Table 5.2. Due to the critical amount of damage involved, bridges with a Damage Rating of greater than 3 are recommended to be replaced as soon as possible.

(4) Relation between sag and span length for unloaded bridge

The Bailey bridge is very flexible structure. Method of maintenance and load restriction are specified strictly, as indicated in "Manual of Bailey Bridges". Therefore, it is essential to know the strength of bridges in regards to the sag/span length ratio, which is shown in Table 5.3. The sag and span length of each bridge was measured by the Study Team. Bridge Nos. 6 and 8 have sag/span ratio of greater than 1/200 and are under very dangerous conditions, therefore it is recommended that these bridges should be replaced or reinforced at the soonest opportunity.

Table 5.2 Results of Damage Rating

	Br.Name	NHRt.No.	Br.Type	Br.Length (m)	Br.Width (m)	Load Capacity (t)	Completion Year	Damage Rating			
								Super	Sub	Bearing	Bridge
1	Kurizampa	1	Bailey TSR	42.7	3.36	5	1971	3.0	2.0	2.4	**3.0**
2	Chamkar Zam	1	Bailey DS	33.7	3.22	5	1973	3.3	1.0	2.4	**3.3**
3	Bjee	1	Bailey TSR	42.7	3.36	9	1969	4.0	1.0	2.4	**4.0**
4	Wachy Zam	1	Bailey DSR	33.7	3.15	18	1969	4.0	1.0	2.4	**4.0**
5	Mangdichu	4	Bailey Susp	97.4	3.20	4	1965	3.7	1.0	0.8	**3.7**
6	Wangdigang	4	Bailey DS	30.5	3.35	15	1969	4.0	1.0	2.4	**4.0**
7	Panjurmani	4	Steel Beam	9.0	4.00	7	1995	-	-	-	-
8	Ishigangchu	4	Bailey DS	36.6	3.34	15	1992	3.0	1.0	2.4	**3.0**
9	Hesothangkha	5	Bailey SS	9.2	3.34	18	1985	1.3	1.0	0.8	1.3
10	Lawakha	5	Bailey DSR	30.5	3.37	18	1988	3.3	1.0	1.6	**3.3**
11	Basochu	5	Bailey SS	18.3	3.34	15	1985	1.3	1.0	0.8	1.3
12	Rurichu	5	Bailey SS	15.3	3.34	18	1987	1.3	1.0	1.6	1.6
13	Baychu	5	Bailey SS	15.3	3.34	17	1985	1.3	1.0	1.6	1.6
14	Kamichu	5	Bailey SS	18.3	3.34	15	1986	1.0	1.0	1.6	1.6
15	Narachu	5	Bailey DS	30.5	3.31	24	1991	1.2	1.0	0.8	1.2
16	Wakleytar	5	Bailey Susp	73.2	3.37	12	1987	2.0	1.0	0.8	2.0
17	Mechikhola	5	Timber Truss	18	3.69	8	1990	1.2	1.0	-	1.2
18	Burichu	5	Bailey DS	27.5	3.37	18	1985	1.3	1.0	0.8	1.3
19	Chanchy	5	Bailey TS	39.7	3.31	18	1986	1.0	1.0	0.8	1.0
20	Loringkhola	5	Bailey DDR	48.8	3.30	18	1992	3.0	1.0	2.4	**3.0**
21	Tangmachu	Mon/Lhue	Bailey Susp	85.2	3.30	12	1982	1.7	1.0	2.4	2.4
22	Sunkosh	Tsil/Sun	Bailey Susp	85.2	3.30	12	1982	2.0	1.0	2.4	2.4

Table 5.3 Relation between Sag and Span Length

Br.No.	Br.Name	NHRt.No.	Br.Type	Br. Length (m)	Br.Width (m)	Load Capacity(t)	Completion Year	Sag (cm)	Span Leng. (cm)	Sag/Span
1	Kurizampa	1	Bailey TSR	42.7	3.36	5	1971	17	4250	1/250
2	Chamkar Zam	1	Bailey DS	33.7	3.22	5	1973	12	3350	1/279
3	Bjee	1	Bailey TSR	42.7	3.36	9	1969	17	4250	1/250
4	Wachy Zam	1	Bailey DSR	33.7	3.15	18	1969	16	3350	1/209
5	Mangdichu	4	Bailey Susp	97.4	3.20	4	1965	51	9740	*
6	Wangdigang	4	Bailey DS	30.5	3.35	15	1969	16	3030	**1/189**
7	Panjurmani	4	Steel Beam	9.0	4.00	7	1995	0	900	N
8	Ishigangchu	4	Bailey DS	36.6	3.34	15	1992	27	3640	**1/135**
9	Hesothangkha	5	Bailey SS	9.2	3.34	18	1985	0	900	N
10	Lawakha	5	Bailey DSR	30.5	3.37	18	1988	7	3030	N
11	Basochu	5	Bailey SS	18.3	3.34	15	1985	2	1810	N
12	Rurichu	5	Bailey SS	15.3	3.34	18	1987	1	1510	N
13	Baychu	5	Bailey SS	15.3	3.34	17	1985	0	1510	N
14	Karnichu	5	Bailey SS	18.3	3.34	15	1986	0	1810	N
15	Narachu	5	Bailey DS	30.5	3.31	24	1991	12	3030	1/253
16	Wakleytar	5	Bailey Susp	73.2	3.37	12	1987	27	7300	*
17	Mechikhola	5	Timber Truss	18.0	3.69	8	1990	0	1760	N
18	Burichu	5	Bailey DS	27.5	3.37	18	1985	10	2730	1/273
19	Chanchy	5	Bailey TS	39.7	3.31	18	1986	16	3950	1/247
20	Loringkhola	5	Bailey DDR	48.8	3.30	18	1992	17	4860	1/286
21	Tangmachu	Mon/Lhue	Bailey Susp	85.2	3.30	12	1982	55	8520	*
22	Sunkosh	Tsil/Sun	Bailey Susp	85.2	3.30	12	1982	37	8520	*

Notes: N: Negligible
*: Suspension Bridge
Bold figure: bigger sag than 1/200

(5) Socioeconomic Conditions around Bridge Sites

In selecting the bridges urgently needing replacement, it is essential to study not only the technical point of view but also the socioeconomic point of view. The survey of social and economic conditions around the 22 bridge sites to identify the role of each bridge in the surrounding community was carried out with the purpose of serving as a factor of selection criteria. The survey was conducted by interviewing the local government staff and residents nearby each bridge site.

The survey results are shown in Table 5.4. From the results it was found that there are many public facilities at bridge sites, such as No.1 Kurizampa, No.2 Chankar Zam, No.3 Bjee, No.5 Mangdichu and No.21 Tangmachu. Moreover, many residences are located near Bridges No.2 Chankar Zam, No.3 Bjee, No.4 Wachy Zam, No.5 Mangdichu, and No.8 Ishigangchu.

Although it is very difficult to weight the socioeconomic factor, based on the socioeconomic data shown in Table 5.4, following bridges are the most important among the 22 bridges at present.

Bridge No.1	Kurizampa
Bridge N0.2	Chamkar Zam
Bridge No.3	Bjee
Bridge No.4	Wachy Zam
Bridge No.5	Mangdichu
Bridge No.8	Ishigangchu
Bridge No.21	Tangmachu

Table 5.4 Situation of Public Facilities around Bridge Sites

Bridge Name	Public Facilitie	Primary School	Jr. High School	High School	College	Hospital	Basic Health Unit (BHU)	Post Office	Govt. Office	Town/Village Office	Bus Terminal	Houses(Shops)
No. 1	Kurizampa	Y	Y				Y	Y	Y	Y		15 (0)
No. 2	Chamkar Zam	Y	Y				Y	Y	Y	Y	Y	400 (30)
No. 3	Bjee	(propose)	Y			Y		Y	Y	Y	Y	350
No. 4	Wachy Zam	Y					Y					200
No. 5	Mangdichu	Y	Y			Y		Y	Y	Y		100
No. 6	Wangdigang											0 (0)
No. 7	Panjurmani											50
No. 8	Ishigangchu	Y					Y			Y		60
No. 9	Hesothangkha								Y			30 (3)
No.10	Lawakha											0 (0)
No.11	Basochu											0 (0)
No.12	Rurichu											6 (2)
No.13	Baychu	Y										labor camp
No.14	Kamichu								PWD guest h.			0(0)
No.15	Narachu											0(0)
No.16	Wakleytar								police office			0(0)
No.17	Mechikhola											labor camp
No.18	Burichu								police office			1 (0)
No.19	Chanchey								police office			labor camp
No.20	Loringkhola											0(0)
No.21	Tangmachu	Y	Y				Y		Y			35 (5)
No.22	Sunkosh						Y	Y	Y			40 (7)

(Note) 1. " Public Facilities " within radius of approximately five(5) km from bridge

2. " Primary School " includes " Community School ".

5.1.3 Identification of Bridges which need Urgent Replacement

In accordance with the criteria for preliminary selection described in 5.1.2, following bridges were selected as urgent need of replacement.

(Note: * indicates major factor of selection.)

(1) Br. No. 1 Kurizampa Bridge on National Highway Route (NH) No. 1

- Limit of load capacity: 5 tons*
- Age: 26 years *
- Damage rating: 3.0*
- Sag/span: 1/250
- Socioeconomic point: High*

5-ton limit and 3.0 damage rating were major factors in selecting this bridge to be included among those in urgent need of replacement.

(2) Br. No.2 Chamkar Zam Bridge on NH No.1

- Limit of load capacity: 5 tons*
- Age: 24 years*
- Damage rating: 3.3*
- Sag/span: 1/279
- Socioeconomic point: High*

5 ton limit and 3.3 damage rating were major factors in selecting this bridge to be included among those in urgent need of replacement.

(3) Br. No.3 Bjee Bridge on NH No.1

- Limit of load capacity: 9 tons*
- Age: 28 years *
- Damage rating: 4.0(worst) *
- Sag/span: 1/250
- Socioeconomic point: Low

The 4.0 damage rating was the worst among all bridges studied. This bridge must be replaced as soon as possible.

(4) Br. No.4 Wachy Zam Bridge on NH No.1

- Limit of load capacity: 18 tons*
- Age: 28 years *
- Damage rating: 4.0*

- Sag/span: 1/209
- Socioeconomic point: High*

4.0 damage rating is worst. Limited load capacity of 18 tons seems rather high considering the existing conditions. Therefore this bridge is included among the twelve in urgent need of replacement.

(5) Br. No.5 Mangdichu Bridge on NH No.4

- Limit of load capacity: 4 ton*
- Age: 32 years*
- Damage rating: 3.7*
- Sag/span: N/A (Not applicable due to suspension bridge)
- Socioeconomic point: High*

4-ton limit of load capacity is very small. The 3.7 damage rating is the factor for replacement.

(6) Br. No.6 Wangdigangchu Bridge on NH No.4

- Limit of load capacity: 15 tons
- Age: 28 years*
- Damage rating: 4.0*
- Sag/span: 1/189*
- Socioeconomic point: Low

Damage rating of 4.0 is the worst. A dangerous sag/span of 1/189 was the major factor for selection.

(7) Br. No. 8 Ishigangchu Bridge on NH No.4

- Limit of load capacity: 15 tons
- Age: 5 years
- Damage rating: 3.0*
- Sag/span: 1/135*
- Socioeconomic point: High*

Sag/span of 1/135 is quite large, and damage rating of 3.0 is great enough to be considered as factor for selection.

(8) Br.No.10 Lawakha Bridge on NH No.5

- Limit of load capacity: 18 tons*
- Age: 9 years
- Damage rating: 3.3*
- Sag/span: Negligible

- Socioeconomic point: Low

3.3 damage rating is great, meriting inclusion among the twelve bridges.

(9) Br. No.16 Wakhaleytar Bridge on NH No.5

- Limit of load capacity: 12 tons*
- Age: 10 years
- Damage rating: 2.0
- Sag/span: N/A (Not applicable due to suspension bridge)
- Socioeconomic point: Low

This bridge is included among the twelve due to its substandard load capacity.

(10) Br. No.17 Mechikhola Bridge on NH No.5

- Limit of load capacity: 8 tons*
- Age: 7 years
- Damage rating: 1.2
- Sag/span: Negligible
- Socioeconomic point: Low

This bridge is included among the twelve due to its substandard load capacity.

(11) Br. No.21 Tangmachu Bridge on NH Mongar to Lhentse

- Limit of load capacity: 12 tons*
- Age: 15 years
- Damage rating: 2.4
- Sag/span: N/A (Not applicable due to suspension bridge)
- Socioeconomic point: High*

This bridge is included among the twelve due to its substandard load capacity.

(12) Br. No.22 Sunkosh Bridge on NH No.5

- Limit of load capacity: 12 tons*
- Age: 15 years
- Damage rating: 2.4
- Sag/span: N/A (Not applicable due to suspension bridge)
- Socioeconomic point: Low

This bridge is included among the twelve due to its substandard load capacity.

The summary of the results is shown in Table 5.5.

In a conclusion, the following bridges were chosen as those in urgent need of replacement, and were studied in order to select the priority projects, the purpose of which is to carry out a feasibility study.

Bridge No.	Bridge Name
1	Kurizampa
2	Chamkar Zam
3	Bjee
4	Wachy Zam
5	Mangdichu
6	Wangdigang
8	Ishigangchu
10	Lawakha
16	Wakleytar
17	Mechikhola
21	Tangmachu
22	Sunkosh

Table 5.5 Results of Evaluation

Br.No.	Br.Name	NHRt.No.	Br.Type	Br.Length (m)	Br.Width (m)	Load Capa-city (t)	Age (Year)	Damage Rating	Sag/Span	S.E. Point
1	Kurizampa	1	Bailey TSR	42.7	3.36	**5**	**26**	**3.0**	1/250	O
2	Chamkar Zam	1	Bailey DS	33.7	3.22	**5**	**24**	**3.3**	1/279	O
3	Bjee	1	Bailey TSR	42.7	3.36	**9**	**28**	**4.0**	1/250	O
4	Wachy Zam	1	Bailey DSR	33.7	3.15	18	**28**	**4.0**	1/209	O
5	Mangdichu	4	Bailey Susp	97.4	3.2	**4**	**32**	**3.7**	*	O
6	Wangdigang	4	Bailey DS	30.5	3.35	15	**28**	**4.0**	**1/189**	
7	Panjurmani	4	Steel Beam	9.0	4.00	7	2	-	N	
8	Ishigangchu	4	Bailey DS	36.6	3.34	15	5	**3.0**	**1/135**	O
9	Hesothangkha	5	Bailey SS	9.2	3.34	18	12	1.3	N	
10	Lawakha	5	Bailey DSR	30.5	3.37	18	9	**3.3**	N	
11	Basochu	5	Bailey SS	18.3	3.34	15	12	1.3	N	
12	Rurichu	5	Bailey SS	15.3	3.34	18	10	1.6	N	
13	Baychu	5	Bailey SS	15.3	3.34	17	12	1.6	N	
14	Kamichu	5	Bailey SS	18.3	3.34	15	11	1.6	N	
15	Narachu	5	Bailey DS	30.5	3.31	24	6	1.2	1/253	
16	Wakleytar	5	Bailey Susp	73.2	3.37	**12**	10	2.0	*	
17	Mechikhola	5	Timber Truss	18.0	3.69	**8**	7	1.2	N	
18	Burichu	5	Bailey DS	27.5	3.37	18	12	1.3	1/273	
19	Chanchy	5	Bailey TS	39.7	3.31	18	11	1.0	1/247	
20	Loringkhola	5	Bailey DDR	48.8	3.30	18	5	**3.0**	1/286	
21	Tangmachu	Mon/Lhue	Bailey Susp	85.2	3.30	**12**	15	2.4	*	O
22	Sunkosh	Tsil/Sun	Bailey Susp	85.2	3.30	**12**	15	2.4	*	

Note: S.E.Point: Socioeconomic Point
N: Negligible
*: Suspension Bridge
Bold figures: Major factors in selecting

5.2 Criteria Formulation for Priority Projects Selection

In the course of selecting the priority projects (priority bridges) among the twelve bridges requiring early replacement, the following points were considered, as described in the Inception Report.

• Existing state

Bridge function	- Road capacity in regards to the existing traffic volume - Presence of sidewalk for pedestrians - Capacity in regards to the existing traffic loading - Possibility of enlarging of bridges
Bridge structure	- Bridge damage rating - Possibility of strengthening of members
Approach roads	- Condition of access and approach to bridges - Availability of alternative route

• Benefit of new bridges

Road network	- Uniform load capacity Uniform limit of load capacity along the same route is vital to road function. In the case of National Highway Route No. 1, which has four bridges, No.1 to No.4, all bridges must be improved or replaced simultaneously. Any bridge left as it is, will cause a major bottleneck along the route.
Social effects	- Benefit to public - Access to public facilities, etc. - Possibility of quick rescue in case of disaster
Economic effect	- Economic effect

• Bridge construction

Socioeconomic Effects on Environment

- Benefit to population
- Environmental pollution and effect on animals and vegetation
- Detrimental effects

Selection criteria will consist of the followings:

(1) Importance of the bridge within the national highway network plan of Bhutan Government policy is a major deciding factor in selection of priority projects within the scheme of the national highway network plan.

Based on the importance of each highway route, the score was decided as follows:

Rank A, NH No.1 :	score is 4
Rank B, NH No. 4 and No.5 :	score is 2
Rank C, other NH :	score is 1

(2) Forecast traffic volume for the year 2020

Forecast traffic volume for the year 2020 is the governing factor for priority projects selection.

Based on the traffic volume, score was decided as follows:

bigger than 300 :	score is 4
bigger than 200 :	score is 3
bigger than 100 :	score is 2
less than 100 :	score is 1

(3) Population benefiting from construction of the bridges

At present, the only population data available is that per Dzongkhag, making it difficult to make more precise estimates of local population benefiting from the project. Therefore in the Study the following two components will be used, namely, population of Dzongkhag and socioeconomic importance point, which was evaluated in 5.1.2 Criteria of Preliminary Selection (5).

Total scores are shown in the following Table.

Score (1) : Dzongkhag population is	bigger than 50 thousand	score is 2.0
	between 20 and 50 thousand	score is 1.0
	less than 20 thousand	score is 0.5

Score (2) : Socioeconomic point High score is 2.0
Low score is 0

Bridge No.	Dzongkhag Population in 2020 (Thousand)	Score (1)	Socioeconomic Point	Score (2)	Total Score
1	68	2.0	High	2.0	4.0
2	18	0.5	High	2.0	2.5
3	23	0.5	High	2.0	2.5
4	33	1.0	High	2.0	3.0
5	18	0.5	High	2.0	2.5
6	18	0.5	Low	0.0	0.5
8	23	1.0	High	2.0	3.0
10	33	1.0	Low	0.0	1.0
16	33	1.0	Low	0.0	1.0
17	33	1.0	Low	0.0	1.0
21	34	1.0	High	2.0	3.0
22	52	2.0	Low	0.0	2.0

(4) Preliminary Economic Evaluation

For economic evaluation there are two indicators, namely NPV and CBR. However, in this evaluation only CBR was used, since NPV yields similar value to CBR.

1) NPV: Net Present Value
This is the balance between the discounted benefit and cost under an assumed discount rate. If value is positive, the project is economically feasible.

2) CBR: Cost Benefit Ratio
This is an indicator obtained by the present value of benefit by value of cost.

CBR 1.0 and more : score is 4
CBR 0.75~1.0 : score is 3
CBR 0.50~0.75 : score is 2
CBR less than 0.5 : score is 1
CBR is no value : score is 0

(5) Present Conditions

The following factors were investigated carefully:

- Limited load capacity
- Bridge age

- Bridge damage rating
- Sag/span ratio

1) Limited load capacity

As shown in Table 5.1, Bridges No.1, 2, 3, 5, 7 and 17 have limited load capacity of less than 10 tons.

load capacity of less than 10 tons :	score is 1
others :	score is 0.5

2) Bridge age

Bridges No.1,2,3,4,5 and 6 are more than 20 years old, although Bailey bridge's life span is usually 15 to 20 years.

Bridge age of more than 20 years :	score is 1
otherwise :	score is 0

3) Damage rating

Damage rating of 3 to 4 :	score is 1
otherwise :	score is 0

4) Sag/span length

Ratio of more than 1/200 :	score is 1
less than 1/200 :	score is 0.5
negligible :	score is 0

(6) Engineering/Technology Difficulty of PWD, Bhutan

Construction difficulty will be examined from the engineering and technological point of view. The most difficult bridge was given a score of 4 points, and non-difficult bridge was given a score of 0.

Span length is bigger than 70 m :	score is 4
between 70 and 20 m :	score is 2
span length less than 20 m :	score is 0

5.3 Selection of Priority Projects

Six factors were chosen for selection criteria, and each factor was given a maximum of 4 points. The examination results are given in Table 5.6. The top five bridges were chosen for the following reasons:

No.1 Kurizampa
This bridge is located on NH Rte. No.1, which is the most important trunk highway in the country, meriting a score of 4.0. Forecast traffic volume for the year 2020 is 169, scoring 2 points. Population to receive the benefit merits 4.0 points. Economic evaluation result is 2. Score for present conditions is 3.5 points. Engineering/technological difficulty is 2 points, since the 50 m bridge length is of medium size. Total score is 17.5.

No. 2 Chamkar Zam
This bridge is also along NH Rte. No.1, therefore meriting 4 points. Forecast traffic volume is 169, scoring 2 points. Although the dzongkhag (district) population is not significant, the bridge is located in the center of Jakar rating 2.5. Economic evaluation result is 2. Score for present conditions is 3.5. Engineering/technological difficulty is 2. Total score is 16.0.

No. 3 Bjee
This bridge is also along NH Rte. No.1, therefore meriting 4 points. Forecast traffic volume is 388, scoring 4.0 points. This bridge is located only 12 km west of Trongsa, scoring 2.5. Economic evaluation is 4. Score for present conditions is 3.5. Engineering/technological difficulty is 2, due to medium bridge length of 50 m. Total score reaches 20.0.

No. 4 Wachy Zam
This bridge is also along NH Rte. No.1 scoring 4 points. Forecast traffic volume is 388, meriting the maximum 4 points. This bridge is located only 19 km east of Wangdue, therefore score for the population to receive benefit is 3 points. Economic evaluation is 4 points. Score for present conditions is 3.0. Engineering/technological difficulty is 2 points. Total score is.20.0

No.5 Mangdichu
This bridge is located on NH Rte. No.4 south-north highway, meriting 2 points. Forecast traffic volume of this bridge is 76, therefore scoring 1. Population benefiting from this bridge scores 2.5 points. Economic evaluation score is 2, and score for present conditions

is 3, and engineering/technological difficulty merits 4 points, due to bridge length of 100 m. Total score is 14.5.

In a conclusion the following bridges have been selected as Priority Projects.

Bridge No.1 Kurizampa
No.2 Chamkar Zam
No.3 Bjee
No.4 Wachy Zam
No.5 Mangdichu

Table 5.6 Score Sheet for Priority Projects Selection

Bridge No.	Bridge Name	Importance in NH network		Forecast Traffic Volume		Population to receive Benefit & SE Point	Economic Evaluation		Present Conditions				Eng'ing Techno Difficulty	Total
									Load Capacity	Age	Damage Rating	Sag/ Span		
		Rank	Score	Vh/day	Score	10 thousar	CBR	Score	Score	Score	Score	Score	Score	
1	Kurizampa	A	4	169	2	4	1.01	4	1	1	1	0.5	2	**19.5**
2	Chamkar Zam	A	4	169	2	2.5	1.24	4	1	1	1	0.5	2	**18.0**
3	Bjee	A	4	388	4	2.5	1.70	4	1	1	1	0.5	2	**20.0**
4	Wachy Zam	A	4	388	4	3	2.08	4	0.5	1	1	0.5	2	**20.0**
5	Mangdichu	B	2	76	1	2.5	0.40	1	1	1	1	0	4	**13.5**
6	Wangdigang	B	2	90	1	0.5	0.44	1	0.5	1	1	1	2	10.0
8	Ishigangchu	B	2	90	1	3	0.44	1	0.5	0	1	1	2	11.5
10	Lawakha	B	2	299	3	1	0.71	2	0.5	0	1	0	2	11.5
16	Wakleytar	B	2	299	3	1	0.56	2	0.5	0	0	0	4	12.5
17	Mechikhola	B	2	299	3	1	2.08	4	1	0	0	0	0	11.0
21	Tangmachu	C	1	78	1	3	-	0	0.5	0	0	0	4	9.5
22	Sunkosh	C	1	117	2	2	-	0	0.5	0	0	0	4	9.5
Score			Max. 4		Max. 4	Max. 4		Max. 4	Max. 1	Max. 1	Max. 1	Max. 1	Max. 4	Max. 24

Note: (1) The CBRs are calculated based on the following assumptions:
- The estimated costs are based on the preliminary study on bridges, and cost disbursement schedules are assumed for one or two years in accordance with each bridge length.
- The benefits are estimated based on the differences of intercity travel distances of heavy vehicles between the case "with" the traffic regulation for heavy vehicles as same conditions at present and the case "without" the traffic regulation for heavy vehicles as a result of constructions of the selected 12 bridges.
- Project life of 30 years.
- Discount rate 15 %.

(2) The CBRs for each bridge are calculated based on the premise that other bridges have been replaced.

CHAPTER 6
ALTERNATIVES

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6.1 Design Requirements

6.1.1 Design Standards, Specifications and Criteria

(1) Review of Bhutanese Standards, Specifications and Relevant Studies Documents

Prior to the establishment of design standards and criteria, the following documents for standards, specifications and relevant studies on bridge design were reviewed:

Standards

- Road Construction Manual(RCM), First Edition, PWD, 1988
- Road Design Manual, First Edition, PWD, 1988
- Field Manual of Road Maintenance, First Edition, PWD, 1988

Specifications

- Standard Specifications and Code of Practice for Road Bridges, Section II Loads and Stresses, The Indian Roads Congress (IRC), IRC : 6-1966, 1990 Edition
- Specifications for Building & Road Works, Public Works Department,
- Specifications for Road and Bridge Works, (Third Revision) , Indian Road Congress, New Delhi, 1997
- Standard Plans for Highway Bridges, Vol. III, Concrete T-Beam Bridges
- Ministry of Shipping & Transport, Road Wing, New Delhi, 1980,
- Drawings and calculation sheets of "Purusari Bridge on Rishikesh ~ Joshimath Road" of Span 42 meters in India

Relevant Studies Documents

- Bridge Construction Project, Feasibility Study,ADB,TA809BHU,
- Techno-Economic Feasibility Study Report, Executive Summary & Report
- April 1988
- Design of Lungten Zampa and Lunjuphakha at Thimphu
- August 1990
- Thimphu to Thashigang National Highway, Feasibility Study, ADB,TA1682-BHU
- June 1993
- Existing Bridges at Sarpang Khola, Aie and Rongangchu in Bhutan, Inspection Reports, December 1996

Also the design criteria of the existing permanent bridges along National Highway Routes No.1, No.2, No.3, No.4 and No.5 were collected and analyzed, as shown in Appendix-D.

6.1.2 Geometric Design Criteria

(1) Road Classification

The proposed bridges and approach roads are to be classified as Class A, National Highways, based on the Road Construction Manual (RCM).

(2) Design Geometry

In the RCM there are several criteria, such as Sight Distance, Stopping Sight Distance, Overtaking Sight Distance, Minimum Radii on Horizontal Curves, Transition Curves, Widening at Curves, Vertical Alignment, Vertical Curves, etc.

However this study is for replacement of the bridges, therefore improvement of roads or approach roads is not included in the scope. Existing road alignment and geometrical design criteria were followed in the geometric design criteria.

Therefore only the following criteria was considered in the design.

1) Vertical Grade

Maximum vertical grade of 6 % was adopted to meet the existing approach road.

2) Consideration of curve radius

In the preliminary design 6.0 m minimum curve radius was selected for the following reasons:

- It is appropriate for the minimizing excavation and cutting of cliffs; in order to ensures more economic and safer construction of approach road.
- If 0.9 m shoulder outside and inside of the curve is paved with 5 cm asphaltic concrete in the case of road curve radius of 6.0 m, it is possible to allow a vehicle curving radius of at least 8.0 m for a heavy vehicle 2.5 m wide and 8.2 m long, as shown in Figure 7.1. In this case it is recommended that a warning sign stating "Sharp Curve, R = 6.0 m and Reduce Speed" be installed.

The following curve radii were decided, since space available for the construction of bridges and keeping smooth traffic on existing bridges and approach roads is very limited:

Bridge No.1	Kurizampa, Right Bank:	R = 8.0 m
Bridge No.3	Bjee, Right Bank:	R = 6.0 m
Bridge No.4	Wachy Zam, Left Bank:	R = 6.0 m
Bridge No.5	Mangdichu, Right Bank:	R = 7.0 m

Otherwise radius is 15.0 m or more.

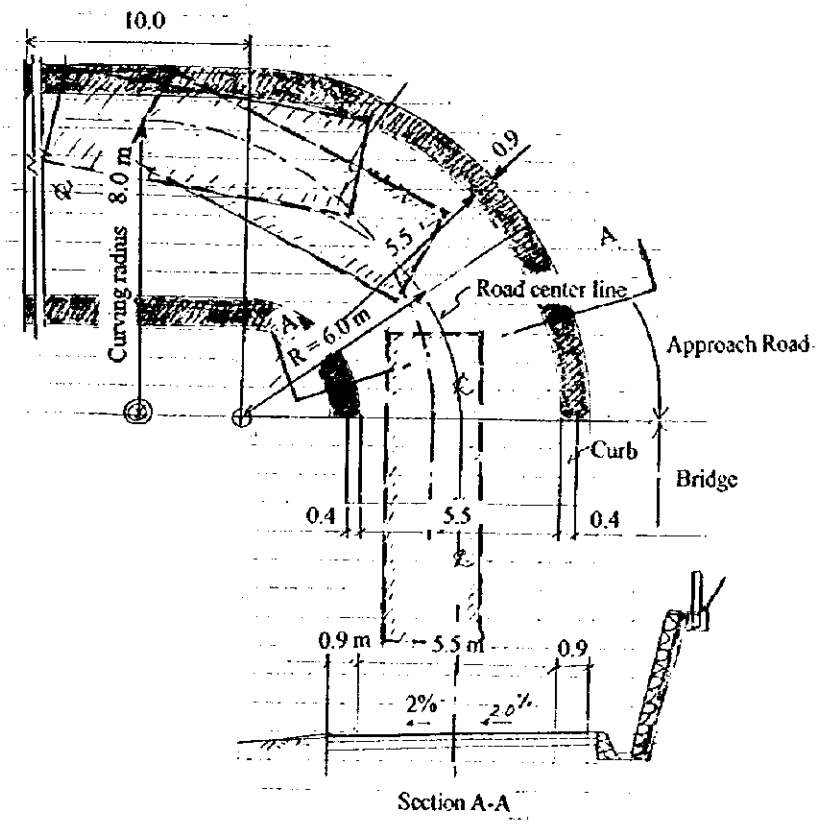


Figure 6.1 Curve Radius 6.0 m

3) Cross section

2 % crossfall on carriageway pavement and 4 % crossfall on shoulders were designed, in accordance with RCM.

4) Typical Cross Section

Typical cross section for proposed bridges and approach roads is shown in Figure 6.2.

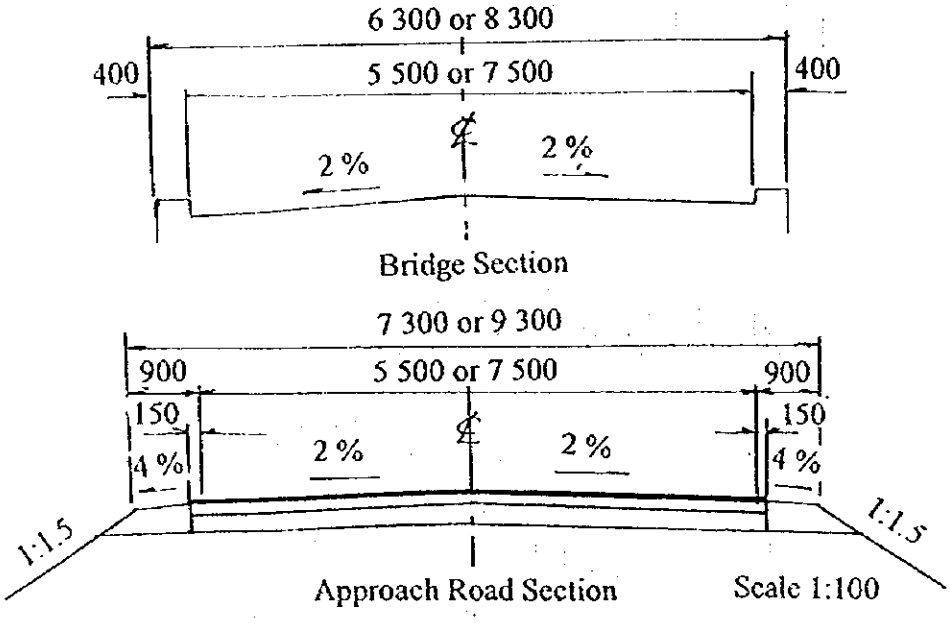


Figure 6. 2 Typical Cross Section of Proposed Bridge and Approach Road

5) Pavement design on approach roads

Thickness of pavement has been designed, based on the RCM (Road construction Manual), according to Class A, national highways and traffic volume of 300 to 500 vehicles per day.

The embankment materials will be provided from the borrow pit around several kilometers from the bridge site. CBR of such subgrade is expected as around 3 to 5 per cent.

1. Thickness of surfacing: In Bhutan for national highways thickness is 5 cm.
2. Thickness of base course and sub base course: 12 cm and 25 cm

Typical cross section is shown in Figure 6.3.

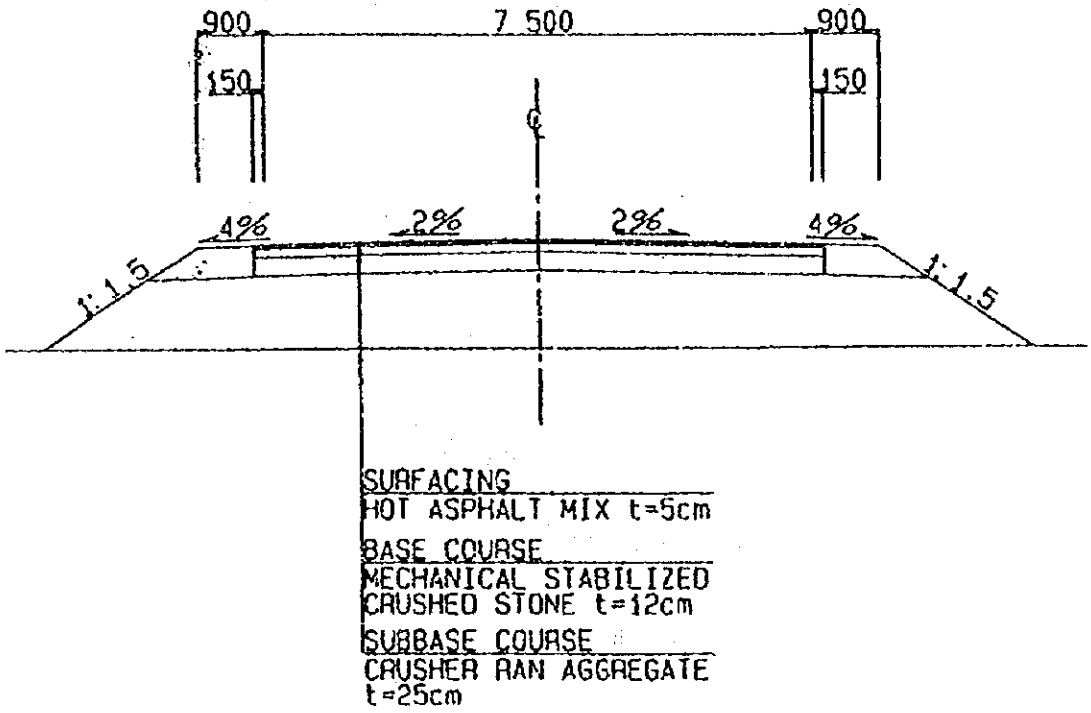


Figure 6.3 Typical Cross Section of Pavement

6.1.3 Bridge Design Criteria

(1) Design Loads

1) Dead Loads

For preliminary design, RCM was used as basic reference except in incomplete cases, in which the IRC codes were used.

2) Live Load

Class A Loading was used in the design. For a reference standard specification and code of practice for Road Bridge Section II is shown in Appendix-E.

3) Impact due to vehicles

Impact factor fraction for steel bridges = 9／(13.5+L)

Where L is the length in metres of the span.

For spans simply supported ------the effective span on which the load is placed.

4) Wind load

Lateral wind force is considered to act horizontally and in such a direction that resultant stresses in the member under consideration are the maximum. Wind pressures and wind velocities are shown below.

Table of Wind Pressures and Wind Velocities

H	V	P
0	80	40
2	91	52
4	100	63
6	107	73
8	113	82
10	118	91
15	128	107
20	136	119

Where H = the average height in metres of the exposed surface above the mean retarding surface (fixed level or ground or bed level)

V = horizontal velocity of wind in kilometre per hour at height of H

P = horizontal wind pressure in kg/m2 at height H

5) Seismic force

Horizontal Seismic Force

Feq = $\alpha\ \beta\ \lambda$ G

Where Feq: Seismic force to be resisted

α : Horizontal seismic coefficient depending on location

β : A coefficient depending upon the soil foundation system

λ : A coefficient depending upon the importance of the bridge

G: Vertical load of structures

in case of Bhutan

α := 0.08, Horizontal seismic coefficient, in Zone V

β : = 1.0, RCC footings on Type I, rocky or hard soils (For N value 30)

λ : = 1.5, Important bridges (due to National Highway Bridges)

Feq = 0.08 x 1.0 x 1.5 G = 0.12 G

Vertical Seismic Force

The vertical seismic coefficient = half of the horizontal seismic coefficient
= 0.06G

(2) Combination of loads and forces

Dead load	G
Live load	Q
Snow load	Gs
Impact due to vehicles	Qim
Wind load	W
Seismic force	Feq

	Permissible increase
Combination (I) = G + Q or Gs + Qim (ordinary loading condition)	Nil
Combination (III) = (I) + W	33.3 %
Combination (IV) = (I) + Feq	50 %

(3) Design Method

The allowable stress design method was used for preliminary design, since there is no requirement in Bhutan's Road Construction Manual (RCM).

(4) Materials

For the structural design at the feasibility study stage the following major construction materials were studied.

i) concrete
ii) reinforcing bars
iii) structural steel

1) Concrete

Only 210 kg/cm^2 was used for foundations, abutment, concrete deck slab and relevant structures. (note: cylinder strength)

2) Reinforcing bars

Mild steel: yield strength 250 Mpa (= 2,549kgf/cm^2)

Hot rolled deformed bar: yield strength 415 Mpa (=4,232kgf/cm^2)

3) Structural Steel

		Permissible tensile stress	Yield point strength	Used to
JIS G3101	SS400	1,400 kgf/cm^2	2,400 kgf/cm^2	Major members
JIS G3106	SM400	1,400 kgf/cm^2	2,400 kgf/cm^2	Major members
JIS G3106	SM490	1,900 kgf/cm^2	3,200 kgf/cm^2	Major members
JIS G3106	SM490Y	2,100 kgf/cm^2	3,600 kgf/cm^2	Major members

(5) Opening

Bridge design was executed, under condition that the opening of the river under bridges will not be decreased than existing opening.

6.1.4 Consideration of Live Load

Following the study in the Interim Report, further study on the Live Load was made in this stage. Comparison was made for bending moment and shearing force, between the Bhutanese Class A Loading, which has decided to be adapted to the preliminary engineering design, and Japanese L-Load (B Live Load), which is commonly used in the design of bridges on national highways and expressways in Japan. As an example, a bridge of 50 m in length and 5.5 m in width was used in the comparison.

The result is summarized as follows:

Since both bending moment and shearing force under Japanese B Live Load are slightly greater than those under Bhutanese Class A Loading, Japanese standards are applied in the details in order to supplement the Bhutanese standards.

Truck axle load survey was conducted at the borders with India, Phunstholing and Samdrup Jonkhar and also in Thimphu in 1987 under the PWD Institutional Strengthening Project.

The results showed that gross vehicle weight of 11 to 15 ton account for 60 per cent of total vehicles at borders.

Against this distribution, the survey result in Thimpu showed that gross vehicle weight in Thimpu was approximately 90 per cent of that at borders.

6.1.5 Consideration of Bridge Width

In the Interim Report, bridge width of 7.5 m was used for the preliminary selection of priority bridges, based on the following reasons:

- Some bridges on national highways have double lane carriageway.
- Proposed Wandue Bridge on National Highway Route No.1 is presently being designed as a double lane bridge.

Future traffic volumes for the year 2020 at the priority bridges, in the interim stage are as follows:

No.1	Kurizampa	169 vehicles / day
No.2	Chamkar Zam	169 vehicles / day
No.3	Bjee	388 vehicles / day
No.4	Wachy Zam	388 vehicles / day
No.5	Mangdichu	76 vehicles / day

Due to low traffic volumes, it is not economical to design 7.5 m wide bridges at present. The reasons are as follows:

- Due to low traffic volume, single lane carriageway is sufficient.
- It would be difficult to widen the entire lengths of National Highway Routes No. 1 and 4.
- Almost all permanent bridges were constructed with 4.5 m bridge width, as follows:
- On National Highway Route No.1, there are 23 permanent bridges. Out of 23 bridges, only one bridge is 6.8 meters in width and another is 6.4 meters. All remaining are 4.5 meters wide.
- On National Highway Route No. 4, there are 13 bridges. All bridges are 4.5 m wide.

Taking the above reasons and the bridge site conditions into account, the following considerations were made in the Study.

(1) Width of bridges less than 50 m in length

According to future traffic volume and bridge site conditions, 4.5 m width for single lane bridge, and 7.5 m width for double lane bridge will be considered, based on the RCM. 4.5 m width for single lane is shown in Figure 6.4, and 7.5 m width for double lanes is shown in Figure 6.6.

(2) Width of bridges more than 50 m in length

Two widths, 5.5 m and 7.5 m will be considered.

Even if a heavy vehicle happens to stop on the bridge for some reason, such as emergency or engine trouble; on a bridge with a width of 5.5 m, other vehicles can move beside the stopped heavy vehicle. Figure 6.5 shows 5.5 m bridge width.

For double lane bridge, 7.5 m width will be considered, as shown in Figure 6.6.

(3) Bridge widths adopted in the Study

The following bridge widths were used in the preliminary engineering design.

Bridge No.	Bridge Name	Bridge Width	Bridge Length
No.1	Kurizampa	5.5 m	54 m
No.2	Chamkar Zam	7.5 m*	43 m
No.3	Bjee	5.5 m	50 m
No.4	Wachy Zam	5.5 m*	43 m
No.5	Mangdichu	5.5 m	100 m

Notes:

1. Width of Bridge No.2 Chamkar Zam

   The bridge site is located in the town area of Jakar. Forecast traffic volume of this bridge is 169 vehicles/day. However this figure is for inter-city traffic volume. According to traffic count survey by PWD in 1997 traffic volumes were 390 vehicles/day. Moreover the number of pedestrians crossing the existing bridge was about 800 persons/day according to additional survey by PWD. The two-lane approach road has also been constructed.

   7.5 m was therefore considered as the width of the proposed bridge.

2. Width of Bridge No.4 Wachy Zam

   Since the road between Wangdue Phodrang and Pelela passes through fragile topography and over soft ground, the bridge at Wachy Zam will be used by heavy machines to maintain road suffering from major landslides during the monsoon periods. Therefore the frequent transport of heavy equipment over the Wachy Zam for the maintenance of landslides requires bridge width over 4.5 m.

   It is reasonable to design this bridge with a width of 5.5 meters.

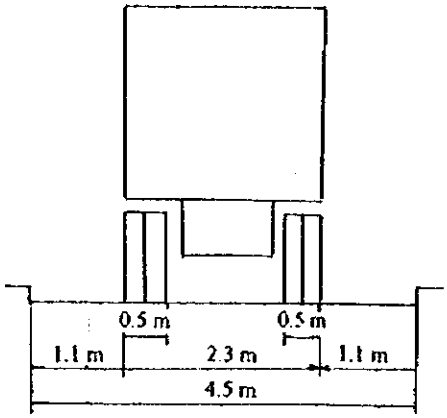


Figure 6.4 4.5 m Bridge Width

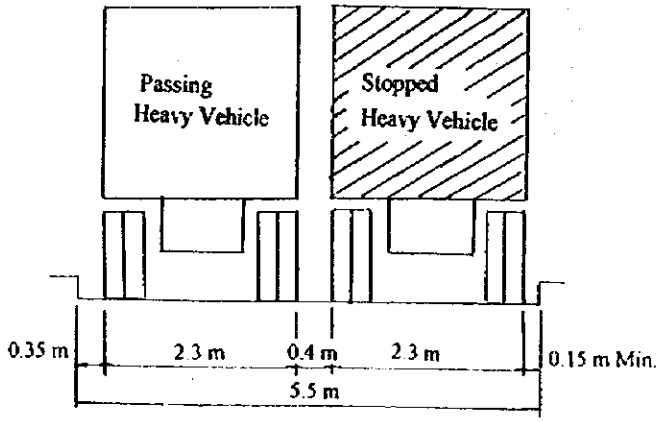


Figure 6.5 5.5 m Bridge Width

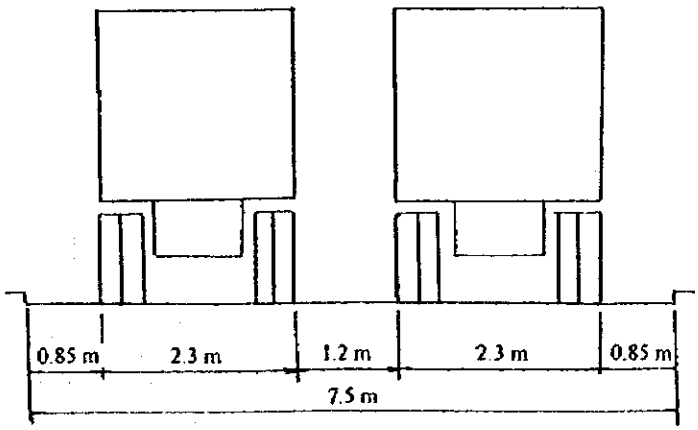


Figure 6.6 7.5 m Bridge Width

6.2 Physical Conditions

6.2.1 Climate and Hydrology

(1) Climate

The climate of Bhutan is influenced by the south-west monsoon and steep mountain features, and varies due to difference of altitude between the south region and the north region. The climate of Bhutan is classified into the following three categories based on its altitude, which ranges from 300 meters to over 6,000 meters above sea level :

- Himalayan Zone

The Himalayan zone (altitude of over 3,000 m) is characterized by severely cold winters and short and cold summers. Areas above 4,250 m are considered non-cultivable, and perpetual snow area extends on areas above approximately 5,500 m.

- Temperate Himalayan Zone

The Temperate Himalayan zone (altitude of 1,500 to 3,000 m) is characterized by moderately warm summers and cool winters. The annual rainfall varies from 500 to 3,000 mm. Temperature varies from below 0 °C to 35 °C. Rice, bananas and oranges grow in rather low areas, and broad-leaved trees are found in the southern slopes of the hilly areas.

- Semi-tropical monsoon Zone

The Semi-tropical monsoon zone (altitude of 300 to 1,500 m) is characterized by high temperature and humidity. The annual rainfall is observed to be above 3,000 mm, and it sometimes reaches 6,000 mm. Tropical jungle covers most of the areas, but there are some dry Savanna-type areas. Temperature is above 15-25 °C throughout the year .

The climate of the Study areas (altitude of 300 to 2,000 m) has both the characteristics of the temperate Himalayan and the semi-tropical monsoon, and it largely varies by difference of altitude. Altitude difference between Wangdue and Pelela pass, and Thrumsengla pass and Mongar are 2,150 m and 2,280 m, respectively.

The passes are characterized by low temperatures, snowfall, dense fog and, but the valleys

have moderate temperatures and more dependable weather. Almost all the bridges in the study area are located in the latter condition.

Table 6.1 shows climate conditions around the 12 bridges.

Table 6.1 Climate surrounding the 12 Bridge Sites

Bridge No.	Bridge Name	Rainfall (mm/month) in rainy season	Average yearly temperature (Degrees C) for a year
1	Kurizampa	Jun ~ Sep 128.4 ~ 168.4	Max : 32.0 Min : 8.4
2	Chamkar	Jun ~ Sep 113.5 ~ 148.5	Max : 24.0 Min : 5.6
3	Bjee	Jun ~ Sep 188.7 ~ 344.4	Max : 24.3 Min : 1.1
4	Wachy Zam	Jun ~ Sep 146.5 ~ 508.6	Max : 23.2 Min : 1.0
5	Mangdichu	Jun ~ Sep 190.7 ~ 288.8	Max : 29.7 Min : 7.8
6	Wangdigang	May ~Oct 106.6 ~ 579.2	Max : 35.1 Min : 9.1
8	Ishigangchu	May~ Sep 90.5 ~ 159.2	Max : 30.7 Min :18.0
10	Lawakha	May~ Jun 99.3 ~ 162.8	Max : 25.6 Min : 5.5
16	Walkeytar	Jun ~ Sep 192.1 ~ 543.7	Max : 24.4 Min : 6.7
17	Mechikhola	Apr ~ Sep 108.2 ~ 635.2	Max : 26.0 Min : 7.1
21	Tangmachu	Jun ~ Aug 144.6 ~ 232.7	Max : 26.7 Min : 3.8
22	Sunkosh	Apr ~ Sep 108.2 ~ 635.2	Max : 25.7 Min : 7.1

Source: Statistical Yearbook Bhutan , 1989 ~ 1995

(2) Hydrology

In Bhutan, all the main rivers, which originate from the glacier of the Himalaya range, flow to the Assam Plains in the south, and join the Brahmaputra River. A number of tributaries from the east and the west join the main rivers.

Ravines are scraped by severe water impact due to the flood water with plenty of debris during rainy season. The gap between the bottom of a river and the top of a mountain is extended as a result.

The Black Mountain range, which extends from south to north in central Bhutan, forms the watershed of river systems dividing into the east and west region. In the western region, the main river system is composed of Torsa River, Wang River and Sunkosh River. In the eastern region, the main river system is composed of Mangdichu River.

The Chamkarchu River and Kurichu River systems merge near the Southern border of Bhutan and India.

In the study area, the bridges crossing the main rivers are Kurizampa Bridge and Tangmachu Bridge on the Kurichu River, Bjee Bridge and Mangdichu Bridge on Mangdichu River, and Wakleytar Bridge and Sunkosh Bridge on Sunkosh River.

The river conditions at the 12 bridge sites are shown in Table 6.2.

Table 6.2 River Condition at the 12 Bridge Sites

Bridge No.	Bridge Name	River Name	River width (m)	Stream condition	Mean water level (m)	High water level (HWL) (m)	Clearance from HWL(m)
1	Kurizampa	Kurichu	43.0	Rapid	8.5	10.5	6.5
2	Chamkar	Chamkarchu	32.0	Rapid	4.0	5.0	5.0
3	Bjee	Mangdichu	25.0	Rapid	2.0	4.0	5.0
4	Wachy Zam	Dangchu	20.0	Rapid	2.0	4.0	10.0
5	Mangdichu	Mangdichu	80.0	Gentle	5.5	10.0	15.0
6	Wandigang	Wangdigang chu	32.0	Rapid	1.0	3.5	15.5
8	Ishigangchu	Ishigangchu	35.0	Rapid	1.5	3.5	8.5
10	Lawakha	Lawakhachu	30.0	Gentle	0.5	1.5	17.0
16	Walkeytar	Sunkosh	69.0	Gentle	4.0	5.0	17.0
17	Mechikhola	Mechikhola	15.0	Gentle	1.0	3.0	5.0
21	Tangmachu	Kurichu	75.0	Gentle	4.0	6.0	10.0
22	Sunkosh	Sunkosh	90.0	Gentle	2.5	4.0	13.5

Source : (1) Survey Result by the Study Team , 1997

(2) Observation Result by Power Division of Ministry of Trade and Industries.

Consideration of the Kurichu Hydro Electricity Project under construction at 7 km downstream was made.

According to the report of the project, the high water level at the Kurizampa Bridge site will not be influenced by the maximum reservoir level.

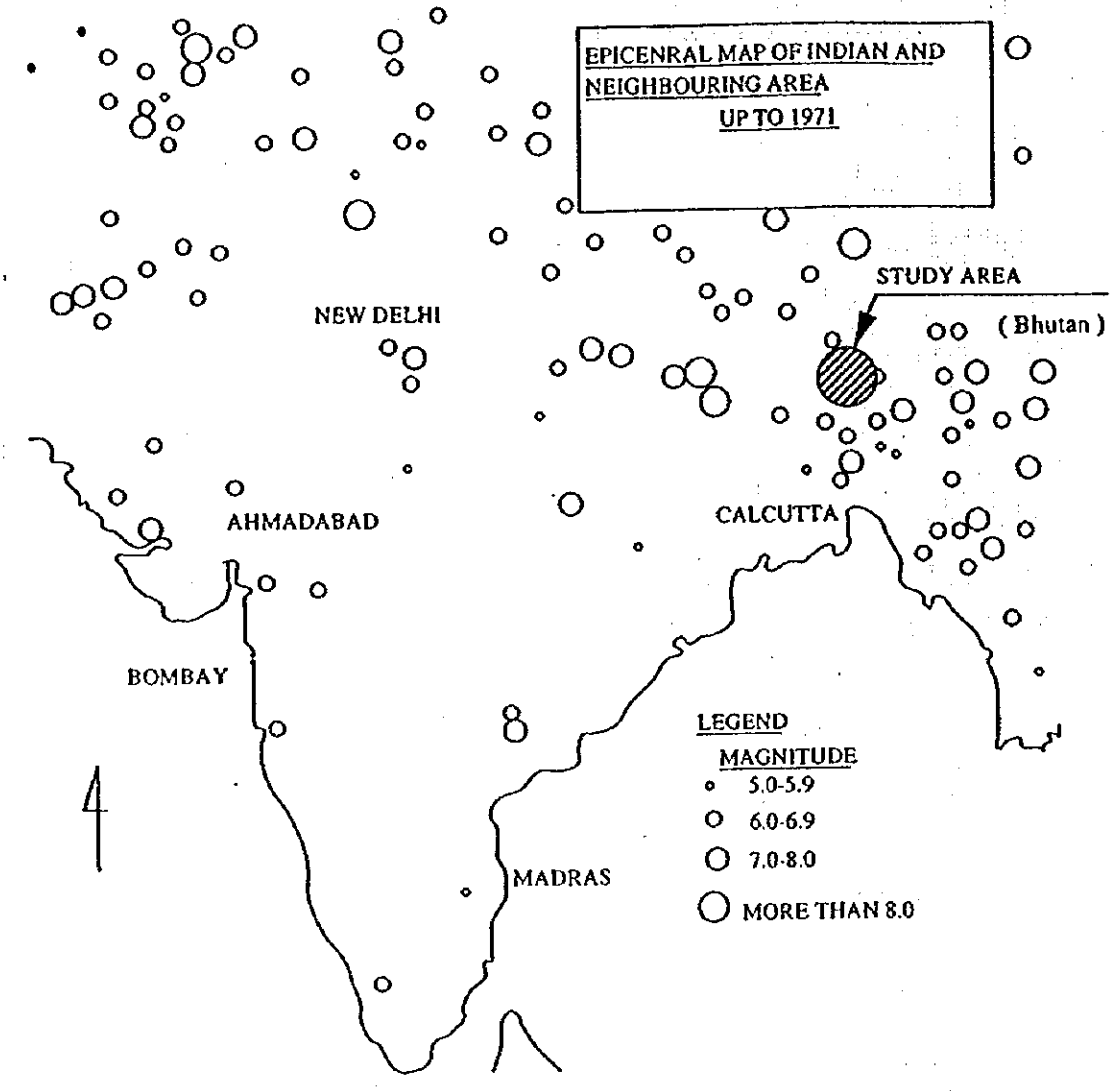
At present, discharge, velocity and flow cross section and water level are being observed by the observation stations installed at 16 places in Bhutan under the Power Division of the Ministry of Trade and Industries .

6.2.2 Earthquakes

In Bhutan, no seismic records exist as earthquake research has not been initiated yet, and therefore it is difficult to grasp the precise occurrence and magnitude of earthquakes .
However, through verbal accounts it is known that several earthquakes of appreciable magnitude have occurred in the past, which sustained heavy losses, particularly collapse of structures.
From the geological standpoint, the structure of the earth's crust in Bhutan seems to be influenced frequently by earthquakes caused by active faults in India and Nepal. There exist in these two countries unstable parts and some devastating earthquakes have occurred. Therefore, it is necessary to review Indian research on seismic activities in the Indian sub-continent. Figure 6.7 shows an epicentral seismic map of the Indian sub-continent.

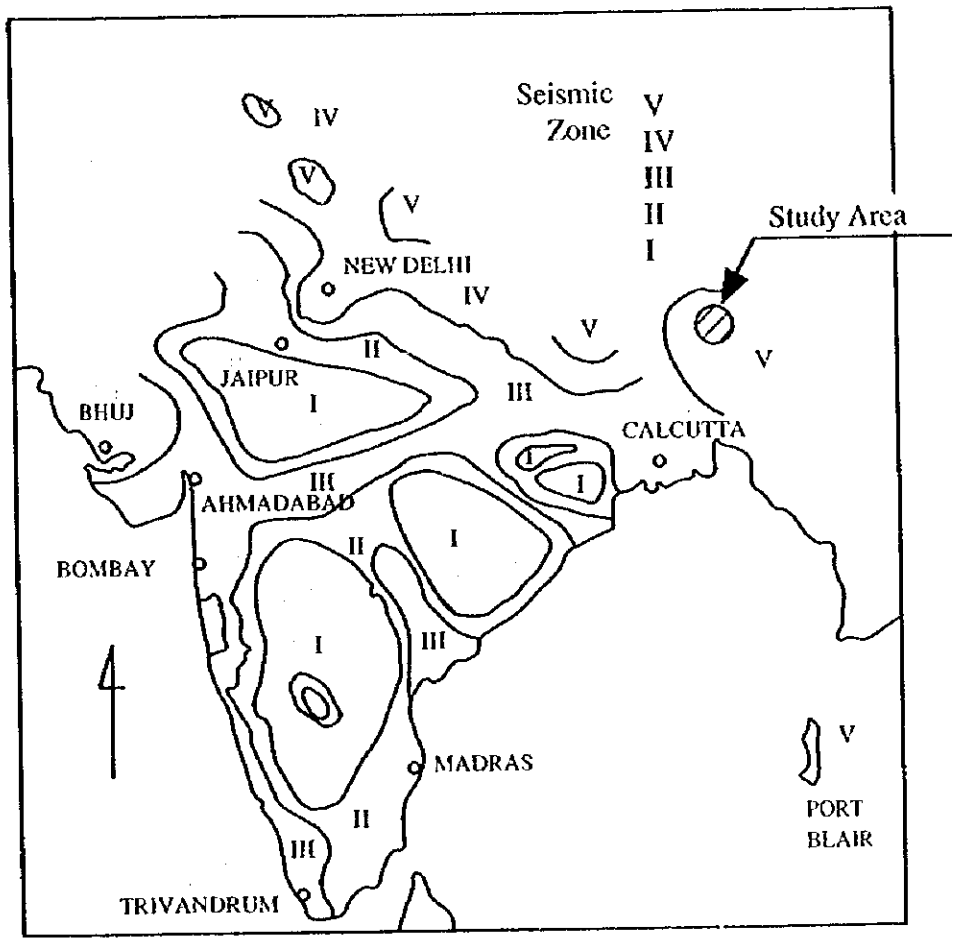
In India, the seismicity at a site is assessed partly by its distance from the faulted rock formations and partly from the frequency and size of shocks that have occurred in the past. The geological zoning of a country depends primarily on the known seismic history of a region, unless there is specific evidence of tectonic features which would be potential causes of earthquake, even if there is no record or known seismic activity.
In determining the nature of activity in the faulted formations of a region, installation of sensitive seismographs is useful. It records small tremors occurring from movements in the faults nearby. Sometimes faults are hidden under alluvium and they can be detected either through seismograph records or through gravity measurements. The faults are indicated through gravity measurements since the faults are associated with anomalous mass distribution which results in change of gravity value from the expected theoretical value.
On the basis of the factors explained above India is divided into five seismic zones as shown in Figure 6.8. The classification of the zones is described in Table 6.3.

For years, structural design in Bhutan often failed to take proper account of structural design requirements and in particular, earthquakes. At present, structure design including buildings and masonry structures in Bhutan is being reviewed for seismic relevance to Bhutan, based on some Indian Standards.



Source : "Elements of Earthquake Engineering" A.R. Chandrasekaran , Professor, School of Research & Training in Earthquake, Engineering University of Roorkee, Roorkee, India , 1976

Figure 6.7 Epicentral Seismic Map of India and Neighboring Area



Source : "Elements of Earthquake Engineering" A.R. Chandrasekaran , Professor, School of Research & Training in Earthquake, Engineering University of Roorkee, Roorkee, India

Figure 6.8 Seismic Zones of India and Neighboring Area

Table6.3 Classification of Seismic Zones

Zones	Description of Earthquake
I	During the day felt indoors by many , outdoors by a few ; at night some awakened ,dishes, windows, doors disturbed ; walls make cracking sound, sensation like heavy truck striking the building ; and standing motor cars rocked noticeably.
II	Felt by all ; many frightened and run outdoors; some heavy furniture moved ; a few instances of fallen plaster or damaged chimneys; and damage slight .
III	Everybody runs outdoors, damage negligible in buildings of good design and construction; slight to moderate in well built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken; noticed by persons driving motor cars.
IV	Damage slight in specially designed structures; considerable in ordinary but substantial buildings with partial collapse; very heavy in poorly built structures; panel walls thrown out of framed structure, heavy furniture overturned , sand and mud ejected in small amounts; changes in well water ; and disturbs persons driving motor cars.
V	Some well-built wooden structures destroyed; most masonry and framed structures with foundations destroyed; ground badly cracked; rails bent; landslides considerable from river banks and steep slopes; shifted sand and mud ; and water splashed over banks Total damage ; waves seen on ground surface ; lines of slight and level distorted and objects thrown upward into the air.

Source : "Elements of Earthquake Engineering " A. R. Chandrasekaran, Professor, School of Research &Training in Earthquake, Engineering University of Roorkee, Roorkee, India

Indian Standards :

- Standard Specifications and Code of Practice for Road Bridges
- Criteria for Earthquake Resistant Design of Structures
- Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice

The PWD recommends that all structures in Bhutan be designed for the requirements of Seismic Zone V.

6.2.3 Topography

(1) General

Bhutan lies between latitudes 26-45-00 and 28-15-00 North, longitudes 80-05-00 and 92-10-00 East.

Bhutan has an area of approximately 46,500 km^2, 330 km from east to west and 180 km from north to south. It borders Tibet on the north and is otherwise surrounded by India. The lowest altitude is 160 m at a points on the border with India. The highest altitude, 7,554 m, is Kulakangri Mountain on the border with Tibet. The altitude difference between the north and the south is great. Geologically, active upheaval movements occurred in Bhutan from Tertiary to Quaternary periods.

Due to this upheaval, rapid streams encroached bottoms of ravines and deep v-shaped ravines were formed in various places in Bhutan. Riverbeds are narrow and of steep gradients and valley plains are very few. The greater part of the national highways in Bhutan pass through steep mountain slopes and precipitous cliff areas.

The topography of Bhutan is classified into three categories of altitude: the southern foothills (less than 1,000 m), the central zone (1,000 m to 4,000 m) and the northern Himalayan region (above 4,000 m). The northern Himalayan region is uninhabitable. The study area is located in the gradual rise from the southern foothills of the central zone.

(2) Highways and Bridges

Route No.1 (Trashigang - Semtokha Highway) crosses a number of rivers flowing from the north. It crosses four main rivers, i.e., Sunkosh, Mangdichu, Chamkarchu and Kurichu, within the study area. Route No.1 goes over four mountain passes, namely Pelela Pass, Yutongla Pass, Thrumshingla Pass and Korilla Pass. The passes and their environs are located between altitudes of 2,300 m and 3,800 m. These are the most treacherous hardest parts of the highway, due to heavy snow and falling rock.

Kurizampa, Bjee and Wachy Zam Bridges, situated along National Highway Route No.1, are in ravines, at relatively low altitudes ranging from 580m to 900m, while Chamkar Zam Bridge is at an altitude of 2,400 m.

The bridges cross Kurichu, Chamkarchu, Mangdichu and Dangchu Rivers. Kurichu and Mangdichu are major rivers in Bhutan. Kurizampa, Bjee and Wachy Zam Bridges are between rocky cliffs while Chamkar Zam Bridge is situated in a flat area adjoining Jakar Town.

Figure 6.9 shows the altitudes of the passes and main cities along National Highway Route No. 1.

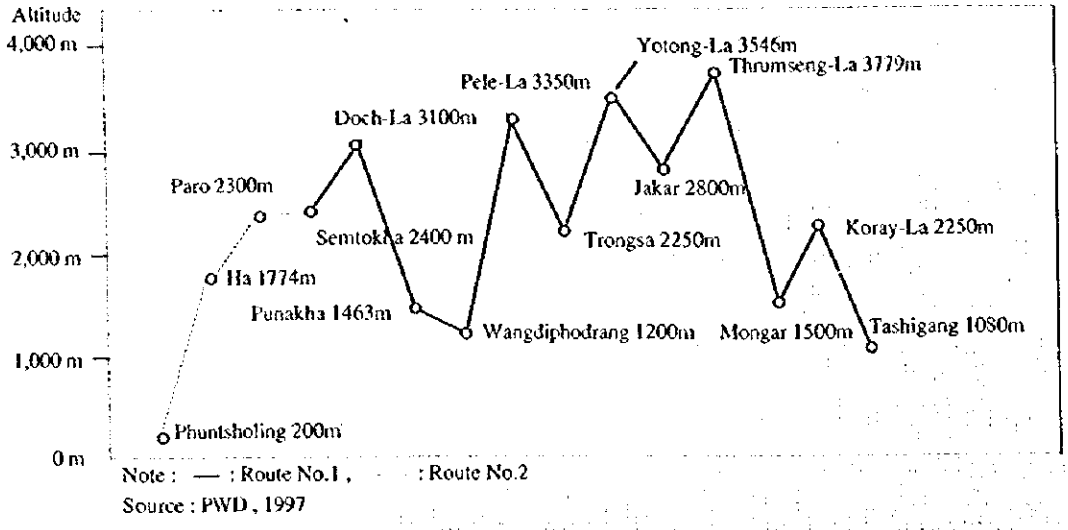


Figure 6.9 Altitude of National Highway Route No. 1

Compared with Route No.1, Route No. 4 and No. 5 have few passes to cross, as they mainly run along the rivers and mountain slopes.

However, the bridges along Route No. 4, i.e., Mangdichu, Wangdigang, Panjurmani and Ishigangchu, are surrounded by more precipitous cliffs.

The altitudes of bridges crossing Mangdichu River range between 500 and 1,000 m. The bridges at Hesothangkha, Lawakha, Basochu, Rurichu, Baychu, Kamichu, Narachu, Wakleytar, Mechikhola, Burichu, Chanchey, Loringkhola, and Sunkosh are all situated along Route No. 5 and are surrounded by cliffs. However, they are in a good highway situation compared with other highways. They cross Sunkosh River or its tributaries. The altitude of these bridges range from 300 to 1,100 m.

Tangmachu Bridge located along the Mongar-Lhuentse Road, which functions as a district road, is situated 52 kilometers from Route No. 1. It crosses Kurichu River and is at an altitude of 1,100 m.

The topographic conditions at the 12 bridge sites are shown in Table 6.4.

Table 6.4 Topographic Conditions at the 12 Bridge Sites

Bridge No.	Bridge Name	Topography	Existing Bridge Surrounding		Land Use surrounding Bridge	
			Left bank	Right bank	Left bank	Right bank
1	Kurizampa	Central zone	Stable slope	Stable cliff	Resident area	-
2	Chamkar Zam	Central zone	Stable cliff	Plain area	-	Residential area
3	Bjee	Central zone	Stable cliff	Stable cliff	-	Residential area
4	Wachy Zam	Central zone	Stable cliff	Stable cliff	-	Paddy field
5	Mangdichu	Central zone	Plain area	Stable cliff	Residential area	-
6	Wangdigang	Central zone	Stable slope	Stable slope	-	-
8	Ishigangchu	Central zone	Unstable slope	Stable cliff	-	-
10	Lawakha	Central zone	Stable cliff	Stable slope	-	-
16	Walkeytar	Southern foothills	Stable cliff	Stable slope	-	-
17	Mechikhola	Southern Foothills	Stable cliff	Stable cliff	-	-
21	Tangmachu	Central zone	Stable slope	Stable cliff	-	Residential area
22	Sunkosh	Southern foothills	Stable cliff	Stable slope	Paddy field	Residential area

Note : "-" means no land use

Source : Survey Result by the Study Team, 1997

6.2.4 Geology

(1) General

The geology of Bhutan is characterized by the collision of the Eurasian Continental Mass and the Indian Continental Mass. Sediments of the Tethys Sea existing between them then were thrust up and the Himalayan Range was formed. Collision of the continents started from the Tertiary Eocene, causing the Himalaya's upheaval area where Bhutan lies.

In the southern area of Bhutan three geological tectonic lines stretch in an east-west direction. In the northern area of Bhutan, metamorphic rocks (gneiss, crystalline, quartzites etc.) of the Indian Continental Mass are widely distributed. Most of the project areas are situated in the northern area.

From the standpoint of geological structure, Bhutan is classified into three categories as shown in Table 6.5. Belts of Frontal Rock, Central Crystalline Rock and Tethyan Rock are distributed from the south to the north in Bhutan.

(2) Geological Classification of the Study Area

The section between Semtoka and Tongsa along National Highway Route No. 1 is composed of the Thimphu Formation which includes migmatites, granite and gneiss with mica-schists and quartzites. A part of the above section is also composed of the Tirkhola Formation, which includes quartzites and lime stones. The section between Tongsa and Mongar is mainly composed of the Thimphu Formation, which includes migmatites, granite and gneiss. However, the section near Ura is composed of the Tirkhola Formation which includes quartzites and lime stones. The Mongar section, after crossing the Main Central Thrust, is composed of the Shumar Structure, which includes quartzites and phyllites.

Route No. 4 from the northern area to the southern area is composed of the Thimphu Structure, including migmatites, granites and gneisses; and the Tirkhola Structure which includes quartzites, lime stones; and the Wachila Structure, which includes limestone, flagstone and metavolcanics.

Route No. 5 runs alongside a river cutting through the Thimphu Formation which includes migmatites, granites and gneisses. Around the Damphu section is composed of the

Tirkhola Formation of quartzites and lime stones is most frequently encountered.

The Mongar-Lhuntshi section is composed of the Shumar Structure which includes quartzites and phyllite. This section crosses the Main Central Thrust, which runs from the west to the east along the southern area of Bhutan, formed when the continents collided as previously mentioned.

Table 6.5 Geological Structure Classification

Belt	Location	Formation	Rock
Tethyan Rock	Occupying the northern - most part and nearby Black Mountain Covering the Higher Himalaya and isolated but large portions of the Lesser Himalaya	• Beli • Shodug • Barishong • Tang Chu • Wachi La • Nake Chu • Tirkhola	• Quartzite,slate,silt stone, sandstone Slates, pebbly slates and dimictites • Quartzites, phyllites to limestone • Slates and limestone • Flagstone, metavolcanics and slates • Quartzites and conglomerates • Bedded quartzites, locally lime stone
Central Crystalline Rock	Occupying the greater part of overall Bhutan distributed northern area from MCT(Main Central Thrust) Occupying portions of the Lesser and Higher Himalaya	• Paro • Thimphu	• Quartz-micaschists, quartzites,calc-silicates, marble with thin beds of graphic schist, with minor migmatization • Migmatites and biotite-granite gneisses with thin beds of quartzite, mica-schist, calc-silicate rocks and marbles
Frontal Rock	Existing southern side from MCT(Main Central Thrust) Making up the foothills and part of the Lesser or Lower Himalaya	• Shumar • Manas • Phuntsholing • Thungsing • Diuri • Damuda • Siwaliks • Alluvium	• Phyllite, green micaceous quartzite • Dolomite and quartzites • Variegated phyllites and quartzites • Quartzites and conglomerates • Gray tilloid boulder slates • Sandstones, shale and coal seams • Thick conglomerates with quartzite/jasper boulders in sandy matrix friable sandstone with few claybeds • Terrace deposits of sand, gravel and boulder

Source : Atras of Mineral Resource of the ESCAP Region , United Nations New York, 1991

(3) Bridge Site Condition

1) Bridge Foundation

From the site investigation, the abutments of most of the 22 bridges are to be direct foundations. Near the bridge sites, bedrock or sand/gravel/boulder layers are exposed at ground level.

The bridges of Chamkar Zam, Mangdichu, Wakleytar, Burichu were built on well-developed terrace deposits found only to one side of the river, bedrock generally occurring on the opposite bank. Bridge foundations on the terrace are situated on sand/gravel layers. Bridge foundations on the opposite bank are situated on bedrock.

The bridges of Bjee, Wangdigang, Panjurmani, Hesothangkha, Rurichu, Kamichu, Narachu and Sunkoch are covered with talus deposits (sand/gravel) on the bedrock. Some of the bridge foundations are to be dug through sand/gravel layers and are situated on bedrock.

The geological conditions of the 12 bridge abutment sites are shown in Table 6.6.

Table 6.6 Geological Condition near the existing abutments

Bridge No.	Bridge Name	Geological Conditions	
		Left Bank	Right Bank
1	Kurizampa	Rock: Fine grained quartzite	Rock: Fine grained quartzite
2	Chamkar Zam	Terrace deposits: Gravel/boulders	Rock: Granite gneiss
3	Bjee	Rock: Granitic gneiss	Talus: Sandy gravel
4	Wachy Zam	Rock: Micaschist	Rock: Micaschist
5	Mangdichu	Terrace deposits: Gravel/boulders	Rock: Fine grained quartzite
6	Wangdigang	Talus: Sandy gravel	Rock: Meta sediment/quartzite
8	Ishigangchu	Rock: Gneiss	Rock: Gneiss
10	Lawakha	Rock: Granitic gneiss	Rock: Granitic gneiss
16	Wakleytar	Terrace deposits: Gravel/boulders	Rock: Meta-sediment
17	Mechikhla	Rock: Quartzite	Rock: Quartzite
21	Tangmachu	Rock: Micaceous quarzite	Rock: Micaceous quarzite
22	Sunkosh	Rock: Quartzite	Talus: sandy gravel

Source : Survey Result by the Study Team, 1997

2) Bedrock at the Bridge Sites

Bedrock type of gneisses and migmatites are numerous, and are distributed extensively. It is assumed that bedrock strength is high from the aspect of the whole bridge, though there appear different-sized bedrock joints at each bridge site.

3) Sand /Gravel Stratum at the Bridge Sites

Existing sand/gravel stratums are divided into terrace stratum and the talus stratum. Terrace stratum is composed of pebble, gravel and sand. Solidity is comparatively high, therefore; it is assumed that the bearing capacity is also high. On the other hand, talus stratums are slipshod deposits composed of rubble, sand and silt. It is assumed that the bearing capacity of these talus layers are not reliable for bridge foundations.

4) Alluvium System at the Bridge Sites

The distribution of alluvial plain in a valley floor is limited and small-scale. Alluviums are composed of thin layers of clay, sand and gravel of limited range.

5) Landslide at the Bridge Sites

Along the Namling section (Route No. 1, Jakar-Mongar), Panjurmani section (Route No.4, Tongsa-Zhemgang) and Shercamp section (Route No. 4 Gelephu-Zhemgang), landslides are observed on the slope mainly of deep talus deposits, mostly occurring during the rainy season .

Landslides at the bridge sites have not been observed except for the Ishigangchu Bridge site (Route No. 4, Tongsa-Zhemgang). The left bank side of Ishighngchu Bridge is situated on an unstable slope thickly covered by talus deposits. At present, these slopes are protected by gabions etc., and so far are stable. Therefore, it is important to avoid slope cutting during bridge construction in order to prevent landslides or deep slope failures. Slope cutting should also been avoid at the other bridge sites so at to maintain slope stability.

6.3 Construction Climate

6.3.1 Status of Highway Construction

(1) Expansion of Road Network

There is over 3,200 km of road in Bhutan, serving almost all district headquarters.

Roads are classified into four categories, namely National Highway (47.5 %), District Road (13.5 %), Feeder Road (36.7 %) and Urban Road (2.3 %)

Road infrastructure is under the jurisdiction of Public Works Division of Ministry of Communications.

During the 7th Five Year Plan (1992 - 1997), a total of 41 km of new road and 450 km of resurfacing was completed.

(2) Bridge Construction

There are 180 bridges along roads in Bhutan. Among them are 59 reinforced concrete bridges (totally 1317 m), 3 prestressed concrete bridges (248 m) and 25 composite bridges of steel and reinforced concrete deck (477 m).

Other than these, many bridges on highways are temporary steel Bailey bridges. The government has a scheme to replace 11 bridges to permanent bridges during the 8th Fiver Year Plan.

6.3.2 Status of Contractors

(1) Local Construction Contractors

Local contractors have been established during the last decade in response to promoting privatization as one of the national policies. With a construction license issued from the Ministry of Trade & Industry and registration with the Construction Development Board (CDB) classified as class A, B, C and Petty depending on their capability, performance and annual turnover, they have undertaken various development projects such as roads, bridges, hydroelectric power stations, sewage, factories, buildings and industrial facilities etc. Unfortunately, there are no experienced private construction companies to execute bridge works, since only a few permanent bridges have been constructed by PWD.

When the new financial year (1 July 1997 – 30 June 1998) began, a total of 867 contractors were registered with CDB, out of which 40 were class A, 41 were class B, 116 were class C and the rest of 670 Petty.

(2) Foreign Contractors

Foreign contractors have been mainly engaged in internationally-aided projects.

Since India is the main donor, some Indian contractors are currently engaged in the government-aided projects such as hydro-power station construction, airport improvement, hospital buildings etc. Other than Indian contractors, the only foreign contractor is a Japanese contractor who has a project office for a recently-completed Grant Aid Project. This office will function only until the expiry of warranty period, after which it is customary for such a contractor to return to his country.

(3) Steel Bridge Fabricators

Since there are no steel fabricators in Bhutan, most steel products are imported from India. The study in the market has revealed that there are 4 reputed steel fabricators in Calcutta, India: Braithwaite & Co, Bridge and Roof Co. Ltd., Hindustan Steelworks Construction Ltd., and Affcons.

6.3.3 Availability of Construction Resources

(1) Availability of Major Construction Resources

1) Construction Materials for Roads and Bridges

Concrete Materials

Cement

Ordinary Portland cement is produced in Bhutan in large quantities where the present supply is much more than the demand. However to meet the requirements in terms of the design strength, due consideration needs to be given to quality of cement used of additives etc..

The outline of the main cement factory under operation is as below:

Name of Enterprise : Penden Cement Authority Limited (PCAL)

Location : Gomtu, Samtse District

Production Capacity : 800 tons per day

Cement is procurable through local dealers or directly from the cement factories directly.

Coarse and Fine Aggregates

Boulder, gravel and sand are available within reasonable distance from the bridge locations, on condition that a royalty of Nu. 80 / Tata truck (= 175cuft = 4.6cum) is paid to the Forestry Division in case the material is to be brought from river bed or quarry site. Hence, coarse and fine aggregates for concrete and road works can be produced in abundance by crushing boulders at sites.

Timber

Timber for temporary work are available on the market. On the other hand, plywood for concrete work must be procured from India. In addition, steel forms which are very useful for mass producing concrete girders and for substructure concrete works at substructure must be imported.

Reinforcing Steel Bars and Structural Steel

Reinforcing steel bars are available on the market, but to procure them it is necessary to order through an authorized agency. Steel bar is generally obtained from India as the landed cost is cheaper and procurement easier than importing one from other countries. Steel bars produced by Tata Steel Industry and Mahindra Rolling Mill consist of mild steel bars with yield strength 250 Mpa (=2,549kgf/cm2), cold twisted bars with yield strength 250 Mpa and hot rolled deformed bar with yield strength 415 Mpa (=4,232kgf/cm2), and the available sizes are 6, 8, 10, 12, 14, 20, 22, 24mm diameter. Furthermore there is usually no quality certification (Mill Sheet) regarding the above mentioned strength.
Structural steel such as angle, channel and H / I section is also supplied from India.
Steel girders for composite bridge of steel and reinforcement concrete and structural steel sections for truss / arch bridge are available only from overseas.

Prestressing Steel Wire

High tension steel wires and prestressing accessories required for prestressed concrete girders are not available on the market. As there are few bridge construction projects of this type, these materials have to be imported from overseas.

Fuel

Generally, fuel such as petrol and diesel oil are imported only from India, and are available on the market. It is distributed through the suppliers of Bhutan Oil Distributors (BOD) and Druk Petroleum, which were established recently.

2) Construction Equipment/Plant for Roads and Bridges

Bhutan intends to go ahead with the mechanization of construction to overcome the shortage of both skilled and unskilled labor. Construction work is often slow by the limited equipment and labourers. On the other hand, the PWD and other larger construction companies possess some construction equipment for transportation, earthwork, road work, concrete work, etc., which are available for hire. However, it is doubtful whether or not it is possible to lease well-maintained construction equipment needed for this project, as it may be engaged for other activities at times. Hence, all limited specialized equipment such as big crane, movable cableway, excavator, mobile concrete mixer, stone crusher, semi-trailer,

truck with small crane, etc., are expected to be brought from abroad.

3) Labour Forces

Labourers

Bhutan suffers from a general shortage of manpower, particularly of skilled labour, which has been a major constraint in the development of the economy. Skilled manpower for carpentry and concrete work required for construction of bridges are available within the country, whereas personnel for specialized activities such as rod binding, fabrication of steelwork, stressing of high tension steel wires and erection of prefabricated girders are required to be brought from abroad. So far, as in all other projects, most of these skilled labours are from India. Additionally, it is difficult to employ farmers in rural areas as common labours in the harvest season (May to October).

Civil Engineers

The diploma engineers from the Royal Bhutan Polytechnic at Deothang and the degree engineers graduating from the Indian engineering universities in the field of electrical, mechanical and civil engineering are limited in number every year. Although annually the percentage of civil engineering graduates is on the increase, they are engaged in various civil works of the government agencies, and thereby facing shortage in the private sector. Thus, sometimes the construction companies employ expatriate, i.e. Indian engineers, to fill the shortage.

4) Transportation and Imported Materials and Equipment

Customs Clearance

There are trading companies in Thimphu, Phuentsoling and Calcutta which some carriers deal with for transportation of international goods into the country.

If the documents (Import License) are in order, clearance time for customs is as follows:

- India : 1 day
- Overseas : 7 days at Calcutta Port

Type of Transportation and Carrying Capacity

The type of transportation vehicles and their carrying capacity are assumed, considering the type of carrier, products and the road conditions as follows:

- Steel Bar etc. (Standard Loads) : Tata truck (Capacity : 8 MT)
- Structural Steel (Length up to 6.5 m) : Tata truck (Capacity : 8MT)
- Heavy Equipment : Trailer with ten wheelers

Transportation Route and Time Required

Imports from the overseas except India are transported by truck from Calcutta to Bhutan, taking 3 to 5 days and covering a distance of more than 800 km.

The time required to connect the transportation routes from Hashimara (18km south of Phuentsholing) to the each district capital related with this Project are described in Chapter 8, Construction Plan and Cost.

5) Quality Control

There is a PWD material testing laboratory where all the instruments for soil test, concrete test and bituminous test are available for concreting design of mix proportion and quality control for building and road works.. However, it is not possible to conduct tensile test of steel, as the universal testing machine has been out of order for a long time.

6.4 Bridge Type Alternatives

(1) Bridge Length and Span Arrangement

1) Bridge Length

Based on the results of bridge site investigation, topographical survey, and geotechnical investigations, the following bridge lengths were decided.

Bridge No.	Bridge Name	Bridge Length
No. 1	Kurizampa	54 m
No. 2	Chamkar Zam	43 m
No. 3	Bjee	50 m
No. 4	Wachy Zam	43 m
No. 5	Mangdichu	100 m

Basically the proposed bridge lengths are to be longer than existing for all five bridges, as the abutments of the existing bridges are located at an unfavorable position for reuse (very close to the river), and proposed bridge abutments are to be located on stable strata and in stable conditions.

2) Span Arrangement

For all of the five priority bridges, the velocity of water is very high, especially in the rainy season, when high water flows transport large and heavy boulders. It is therefore costly and dangerous to construct piers in the river. Fortunately, river width is not too wide, and a single span is technically and economically reasonable at all bridge sites.

(2) Comparison between Steel Bridge and Concrete Bridge

For the five (5) priority project bridges, the following restrictions exist.

1) Spaces to be used as a stock pile area for materials, reinforcing steel and formwork workshops, and the fabrication yard are very limited at proposed bridge sites and along the rivers.
2) Concrete strength in the structures built by PWD is generally as low as 210 kg/cm^2 since almost all structures are of reinforced concrete.
3) Due to the road and transportation conditions in Bhutan, the maximum length of materials to be transported is generally only 6 m.
4) Due to the same reason, maximum capacity of cranes is generally 20 to 25 tons.

The comparison between steel bridge and concrete bridge is shown in Table 6.7.

(3) Comparison in Construction Plan and Cost between Concrete Bridge and Steel Bridge

Comparison result is shown in Table 6.8. Method of concrete bridge erection is shown in Figure 6.10.

As a conclusion, steel structures were employed for all priority bridges in the preliminary design, based on the above-mentioned reasons.

(4) Bridge Type Alternatives

1) Superstructures

The relation between steel structure type and reasonable span length, considering the construction cost, construction method, and aesthetic aspect; is shown in Table 6.9.

There are several types of superstructure of steel bridge. However, as mentioned before, in the Study only a single span is considered for bridge type selection.

Table 6.9 Relation of Steel Structure Type with Span Length

Span (m) / Type	20	40	60	80	100	120	140	160	180
Plate Girder									
Truss (Pony)									
Truss									
Langer									
Lohse									

Note: For single span only

Based on the relationship as shown in Table 6.9, the following types were considered for the selection of bridge alternatives.

For bridge length between 40m~ 50m : Plate girder, truss or pony truss

For bridge length between 90m~100m : Langer or Lohse

Comparisons of bridge types are shown in Table 6.10 and Table 6.11.

Comparison between pate girder and pony truss is shown in Table 6.12.

Finally, truss for bridge length of 40 to 50 meters, and Lohse for bridge length of 90 to 100 meters were adopted.

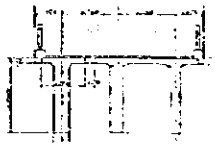
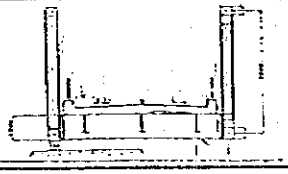
Table 6.7 Comparison between Steel Bridge and Concrete Bridge (1)

Item	Steel Bridge	Evaluation	Concrete Bridge	Evaluation
1. Past experiences by PWD	・Many steel bridges	O	・No prestressed concrete bridges ・Concrete strength is low (210kg/cm^2)	X
2. Construction period	・Shorter	O	・ Longer	-
3. Transportation	・Easy to transport prefabricated steel members	O	・Difficult to transport prefabricated concrete members	X
4. Quality control	・good control in the factory, less control necessary on the site.	O	・Severe control is required on the site.	X
5. Maintenance Management	・Repainting is required (Every 5 to 7 years)	X	・Less maintenance required	O
6. Construction site space	・Smaller space required for equipment and materials	O	・Bigger space required for equipment and materials	X
7. Bridge erection (including temporary works and facilities)	・Member to erect is lighter than concrete member ・Reasonable size of equipment and facilities are required.	O	・Member to erect is heavier. <u>For 40 to 50 m bridges</u> Post tensioned girders Very heavy, and huge erection equipment and facilities required, and difficult. <u>For 90 to 100 m</u> Concrete arch or rigid frame Very heavy equipment and facilities required.	X

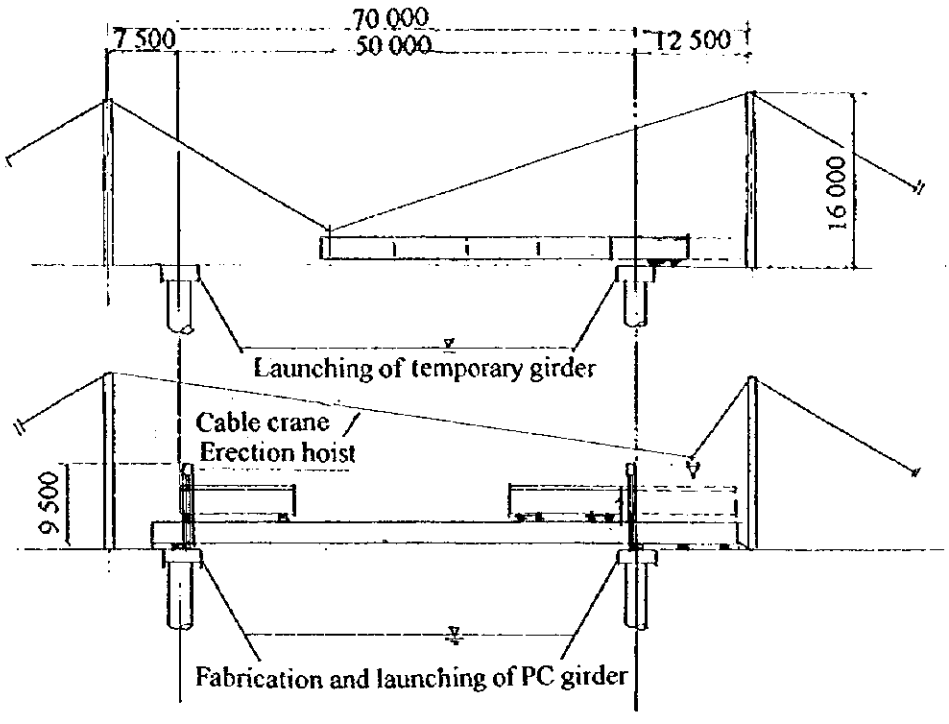
For the above reasons steel bridges have been selected for all priority bridges.

Table 6.8 Comparison between Steel Bridge and Concrete Bridge (2)

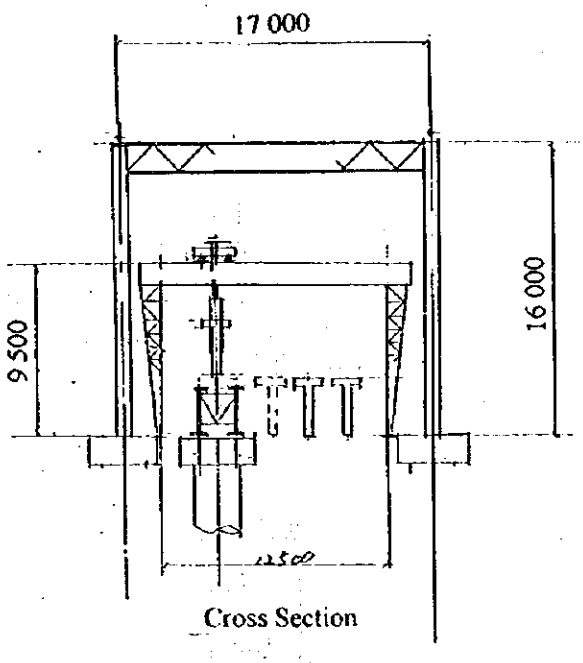
Bridge length of 50 m and bridge width of 5.5 m was used for comparison.

Item	PC Girder	Steel Truss (Pony)
Girder shape		
Girder weight	175 t x 3 no = 525 t	105 t
Fabrication	Cast in situ	In the factory
Erection method	・Construct temporary steel girder with cable crane ・Cast PC girder segment (1/5 of girder length) behind abutment ・Launch PC segment on the temporary steel girder ・Prestress on PC girder	・Erect truss with cable crane
Quality Control	Severe control of prestressing, concrete, form, re-bar,etc.	Less quality control on the site than PC girder
Equipment ・Cable crane ・Truck crane ・Others	 Carrier capacity 30 t Capacity 60 t temporary steel girder, Pre-stressing, grout, etc.	 Carrier capacity 5 t Capacity 16 t -
Construction period	11.5 months	4.0 moths
Approx. cost - Girder manufacture - Girder transportation - Girder erection - equipment transport - Formwork - Bridge Engineer - Bridge Supervisor Total	(unit: Million Nu.) 11.8 0 41.9 6.3 1.9 3.9 6.8 72.6	(unit: Million Nu.) 19.8 4.7 18.3 2.1 0 1.8 3.2 49.9
Concrete strength	at least 350 kgf/cm2 needed. Cement to be imported from India	210 kgf/cm2 for deck slab

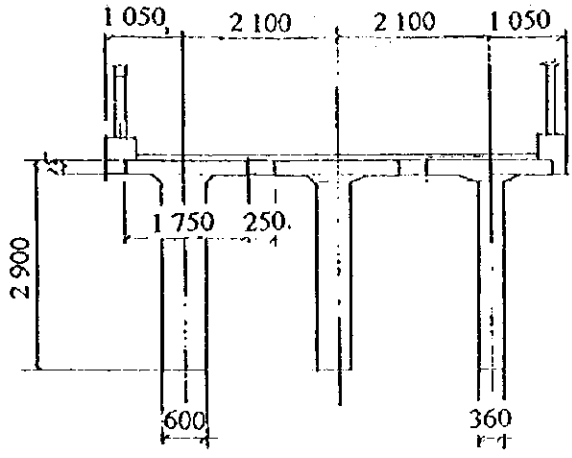
As a conclusion, Steel Pony Truss is recommendable.



Elevation



Cross Section

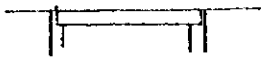
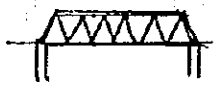
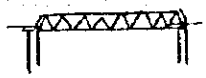


Bridge End Bridge Center

Typical Cross Section

Figure 6.10 Erection Method of PC Girders

Table 6.10 Bridge Type Alternatives for Bridge Length 40 to 50 m

Item	Plate Girder	Truss	Truss (Pony)
Shape			
1. Economical span length (m)	25 to 45	55 to 85	35 to 60
2. Structure height	2.2 to 2.8	7.5	4.0 to 5.0
3. Height/span ratio	1 over 18	approx. 1 over 6	1 over 10
4. Aesthetic view	・Good	・Not so good due to high structure/length ratio (side view)	・Good, slender shape (side view)
5. Bridge erection	・Heavier steel members ・Difficult, higher cost	・Lighter steel members	・Lighter steel members
6. Transportation	・Heavier steel members ・Difficult, higher cost	・Lighter steel members	・Lighter steel members
7. Steel weight (kg/m2)	430	450	380
7. Cost	Expensive	Expensive	Reasonable
Evaluation	X	X	O

For simple beam only

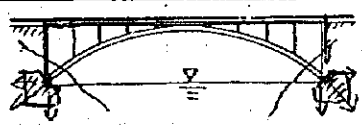
Table 6.11 Bridge Type Alternatives for Bridge Length 90 to 100 m

Item	Langer	Lohse
Shape		
1. Economical span length	70 to 120	80 to 150
2. Structure height	16	16
3. Height/span ratio	1 over 6.5	1 over 6.5
4. Aesthetic	・Good	・Excellent
5. Bridge erection	・Lower chord is bigger than upper chord. Lower chord is not easy to handle. ・Higher cost	・Height of upper and lower chord is similar, Easy to handle members
6. Transportation	・Same as above ・Higher cost	・Same as above
7. Steel Weight (kg/m2)	700	580
8. Cost	Expensive	Reasonable
Evaluation	X	O

For simple beam only

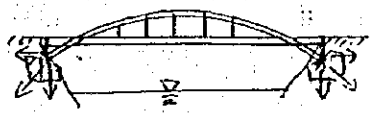
Notes:

Carriageway above Lohse



・Not feasible, due to flood influence on structure
・Not feasible, due to graet lateral reaction to sand/ gravel strata

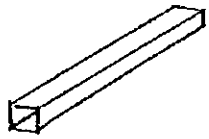
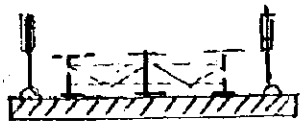
Carriageway at middle heigh of Lohse



・Not feasible, due to graet lateral reaction to sand/ gravel strata

Table 6.12 Comparison between Plate Girder and Pony Truss

Total of Bridge Nos. 1 to 4 were used for comparison.

Item	Plate Girder	Truss (Pony)
Girder shape	0.9m wide x 2.8m high x 8.5m long (6 ton) 	0.45m x 0.45m x 7.0 m long (2.5 ton) 
Girder weight	477.4t	427.6t
Erection method	・Erect plate girder with a upportin beam with cable crane 	・Erect truss with cable crane
Transportation	・Approx. 70 % more cost for steel girder and equipment than truss	
Equipment ・Cable crane ・Truck crane ・Others	 Carrier capacity 10 t Capacity 35 t Supporting girder, etc.	 Carrier capacity 5 t Capacity 16 t -
Construction period	22 months for erection	16 months for erection
Approx. cost - Girder manufacture - Girder transportation - Girder erection - - equipment transport - Mechanic to dismantle mantle 35 t crane for transportation Total	(unit: Million Nu.) 66.2 29.9 83.1 9.3 2.9 191.4	(unit: Million Nu.) 80.6 18.4 55.3 5.0 - 159.3
Bridge elevation and approach road	Due to 2.8 m high girder, approx. 1.5 m higher bridge elevation required, causing longer approach road.	

2) Substructures

Based on the results of topographic and geotechnical survey of five bridge sites, it was found that bearing strata for the substructures are gravel/boulders and rock, and the bearing strata is not so deep from existing ground level. Therefore ordinary abutments were adopted as substructures, since this type is economical.

The following type of abutments were adopted in the preliminary engineering design.

Inverted T abutment : for abutments with height between 6 m and 8 m

Abutment on deep foundation piles: for abutments with height over 8 m

When the bridge length is decided, the location of abutment and slope of river banks and bearing strata was carefully considered for the following reasons:

- It is dangerous to design shorter bridge length with higher abutment height at steep river banks, considering only the economical design.
- As a basic rule in the abutment planning, the lateral allowable width "S" is to be taken as shown in Figure 6.10.

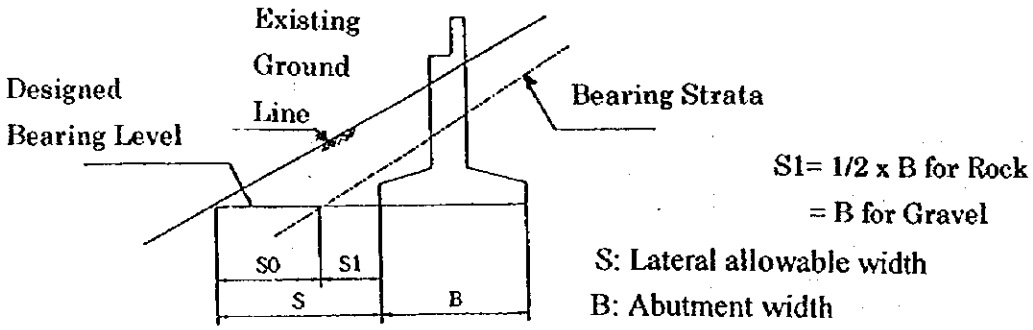


Figure 6.11 Reasonable Abutment Location on Slope

3) Foundations

For Bridge Numbers 1, 3, 4 and 5, Deep wells (Cast in situ manually bored wells) were designed for the abutments higher than 8 m in order to minimize the excavation for abutments and to maintain space for traffic diversion around abutments, since area available for construction at these bridge sites is very limited.

4) Deep Wells

As mentioned in Chapter 6, deep foundation piles were adopted in the design in order to minimize excavation for abutments and to provide a space for traffic around abutments.

Figure 7.4 shows comparison of excavation volume between ordinary abutment and abutment on deep foundation piles in the case of Bridge No.5 Mangdichu.

In deciding the foundation level, the bottom of deep foundation piles or inverted T abutments were designed so as to sit on the bearing strata, which extend as a "key" into the rock or stable gravel layer about one meter.

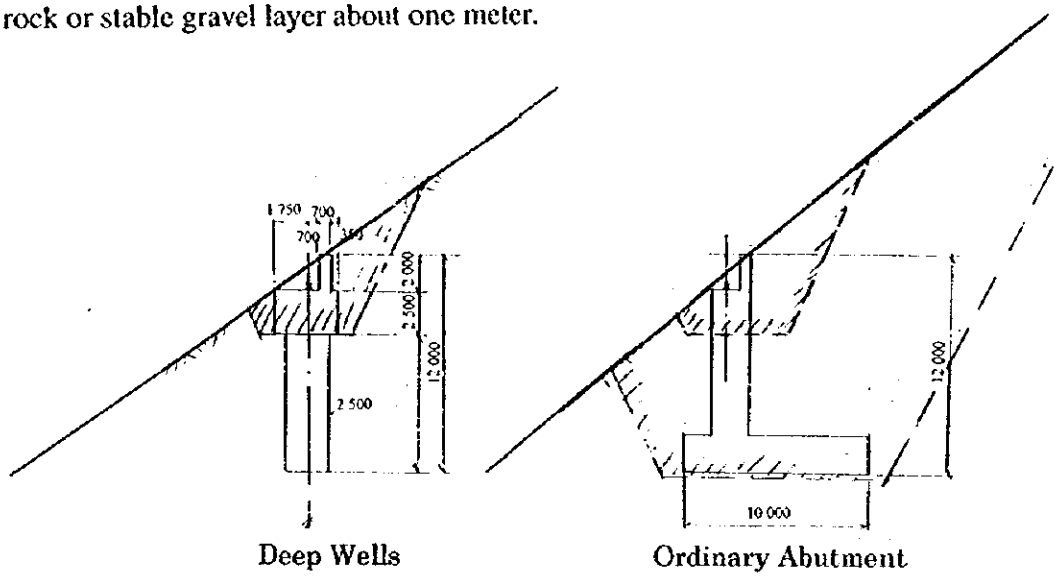


Figure 6.12 Excavation volume

6.5 Alignment Alternatives

The proposed bridge alignments were studied, and the most suitable alternatives were selected based on the results of the bridge site survey, topographical survey and geological survey.

The plans of alignment for each bridge are shown in Figures 6.13 to 6.17.

(1) No.1 Kurizampa

For this bridge, there are three alternatives;

Alternative 1 : To shift the existing bridge to the location of A-1, and construct a new bridge at the existing bridge location A-2,

Alternative 2: To construct a temporary bridge at approximately 1 km downstream, and construct a new bridge at the existing bridge location,

Alternative 3 : To construct a new bridge at approximately 40m downstream.

Characteristics of the above alternatives are shown in the following Table 6.13.

Table 6.13 Characteristics of Alignment Alternatives of Bridge No.1

Items	Alternative 1	Alternative 2	Alternative 3
Road Geometric Conditions	Vertical and horizontal alignment and gradient are the same as that of the existing road.	For temporary bridge, access to the existing road of the right bank side has steep vertical gradient.	Vertical and horizontal alignment and gradient are almost the same as that of the existing road.
Foundation	Exposed rock mass exists. For temporary bridge, rock mass exists.	Exposed rock mass exists. Underground condition of the temporary bridge is stable.	Underground condition of the new bridge is stable. Hard rock exists.
Scouring & Depth of River	For temporary bridge, the right bank scoured by the water impact. Depth of river is about 12m.	Water depth from the river bed is about 12m.	Water depth from the river bed is about 12m.

Cutting & Embankment	Retaining wall on the road of the left bank side should be installed to protect slope cutting portion. For temporary bridge, embankment and retaining wall should be installed	For temporary bridge, embankment and retaining wall should be installed.	Retaining wall on the left bank side should be installed to protect slope cutting portion.
Land Acquisition & Compensation for Property	Not Necessary	Not Necessary	Not Necessary
Existing Traffic Flow	During temporary bridge construction, traffic will be temporarily blocked for one night.	During the bridge construction, existing traffic will not be blocked.	During the bridge construction, existing traffic will not be blocked
Access to the Neighboring Settlements	Accessibility to the settlement areas and major towns are the same as that of the existing road.	Accessibility to the settlement areas and major towns are the same as that of the existing road.	For temporary bridge, accessibility to the settlement areas and major towns are almost same as that of the existing road.
Bridge & Approach Road Length	Lengths are almost the same as that of the existing road.	Lengths are almost the same as that of the existing road.	Lengths are almost the same as that of the existing road.

Based on the overall evaluation, Alternative 1 is the most recommendable at this moment.

(2) No.2 Chamkar Zam

The proposed bridge location, which has no alternative, is approximately 8m downstream. The proposed bridge length will be about 37 to 40m.

(3) No 3 Bjee

The proposed bridge location, which has no alternative, is approximately 8m downstream (A-1). The proposed bridge length will be about 45 to 59m.

(4) No.4 Wachy Zam

There are three alternatives ;

Alternative 1 : To construct a new bridge at location A-2

Alternative 2 : To shift the existing bridge to location A-2, and construct a new bridge at the existing bridge location A-3,

Alternative 3 : To construct a new bridge at location A-1, and construct a new approach road in the rice paddy

Characteristics of the above alternatives are shown in the following Table 6.14:

Table 6.14 Characteristics of Alignment Alternatives of Bridge No.4

Items	Alternative 1	Alternative 2	Alternative 3
Road Geometric Conditions.	Vertical and horizontal alignment and gradient are the same as that of the existing road.	Vertical and horizontal alignment and vertical gradient are almost the same as that of the existing road. Access to the village road on the left bank side is needed.	Vertical and horizontal alignment and vertical gradient are almost the same as that of the existing road. Access to the village road on the left bank side is needed.
Scouring & Depth of River	Scouring is not prominent at present. Maximum water depth is about 4m.	Scouring is not prominent at present. Maximum water depth is about 4m.	Scouring is not prominent at present. Maximum water depth is about 4m.
Cutting & Embankment	New embankment with retaining wall is required, long on right bank, and short on left bank.	It will require the same embankment sections as that of the existing embankment.	New embankment section will become longer than that of other alternatives.
Land Acquisition & Compensation Property	Acquisition is required. PWD has to negotiate with the farmers in Wangdue.	For the temporary bridge, land is required to be leased for 1 year. PWD has to negotiate with the farmers in Wangdue.	Acquisition is required. PWD has to negotiate with the farmers in Wangdue.
Existing Traffic Flow	During new bridge construction, the existing traffic will not be blocked.	During temporary bridge construction, the existing traffic will be temporarily blocked for one night.	During new bridge construction, the existing traffic will not be blocked.
Access to the Neighboring Settlements	Accessibility to the settlement areas and the major towns are the same as that of the existing road.	Accessibility to the settlement areas and the major towns are the same as that of the existing road.	Accessibility to the settlement areas and the major towns will be almost the same.

Bridge & Approach Road Length	Lengths are almost the same as that of the existing road.	Lengths are almost the same as that of the existing road.	Length of approach road is longer than other alternatives.

Based on the overall evaluation, Alternative 1 is the most recommendable at this moment.

(5) Bridge No.5 Mangdichu

There are 3 alternatives ;

Alternative 1 : To construct a new bridge on location A-1,

Alternative 2 : To construct a new bridge on location A-2,

Alternative 3 : To construct a new bridge on location A-3.

Characteristics of the above alternatives are shown in the following Table 6.15:

Table 6.15 Characteristics of Alignment Alternatives of Bridge No.5

Items	Alternative 1	Alternative 2	Alternative 3
Road Geometric Condition.	Horizontal alignment will be shifted to 8m upstream. Realignment of road around the Chorten is necessary.	Horizontal alignment will be shifted to 8m down stream.	Horizontal alignment will be shifted to about 60m downstream.
Foundation	The exposed rock mass on the right bank side is stable though the surface of rock has many cracks.	The ground stratum till the depth of 18m from the road surface on the right bank side seems unstable due to the existence of serious fractures on the surface.	Ground condition on the right bank side is stable.
Scouring & Depth of River	Scouring is not prominent at present, but on the left bank side slope protection should be provided to prevent scouring. Depth is about 10m.	Scouring is not prominent at present, but on the left bank side slope protection should be provided to prevent scouring. Depth is about 10m.	Scouring is not prominent at present, on both the bank side slope protection should be provided to prevent scouring. Depth is about 10m.

Cutting & Embankment	Embankment section on the left bank side and cutting section on the right bank side requires adjustment in the vertical alignment. Cliff on the right bank side should be cut and widened to make working space.	Embankment section on the left bank side and cutting section on the right bank side requires adjustment in the vertical alignment. Cliff on the right bank side should be cut and widened to made working space.	Embankment section on the left bank side and cutting section on the right bank side requires adjustment in the vertical alignment. Cliff on the right bank side should be cut and widened to make working space.
Land Acquisition & Property Compensation	Alignment passes through the PWD land on the left bank side. Police house on the right bank should be relocated.	Alignment passes through the PWD land on the left bank side. PWD house should be relocated.	Alignment passes through the PWD land on the left bank side. PWD houses should be relocated.
Existing Traffic Flow	To keep the existing traffic flow, the construction method should be planned carefully.	To keep the existing traffic flow, the construction method should be planned carefully.	To keep the existing traffic flow, the construction method should be planned carefully.
Access to the Neighboring Settlements	Accessibility to the settlement area and major towns are the same as that of the existing road.	Accessibility to the settlement area and major towns are the same as that of the existing road.	Accessibility to the settlement area and major towns are the same as that of the existing road.
Bridge & Approach Road Length	Approach road length is longer than Alternative 2.	Approach road length is shorter than the other Alternatives.	Approach road length on the left bank is longer than Alternative 2.

Alternative 3 is the most recommendable at this moment as based on the overall evaluation.

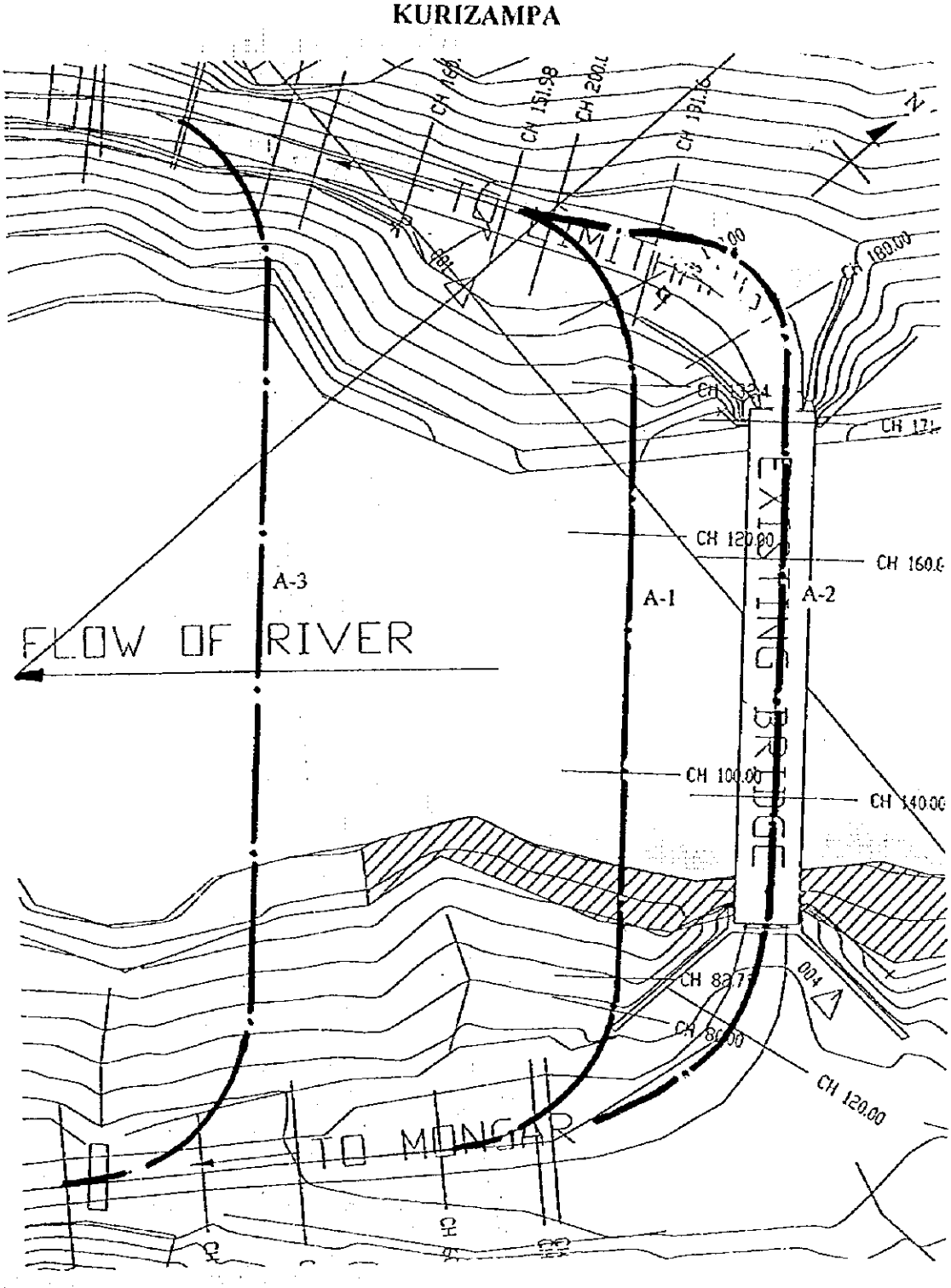


Figure 6.13 Plan of Alignment Alternatives for Bridge No. 1 Kurizampa

(Not to scale)

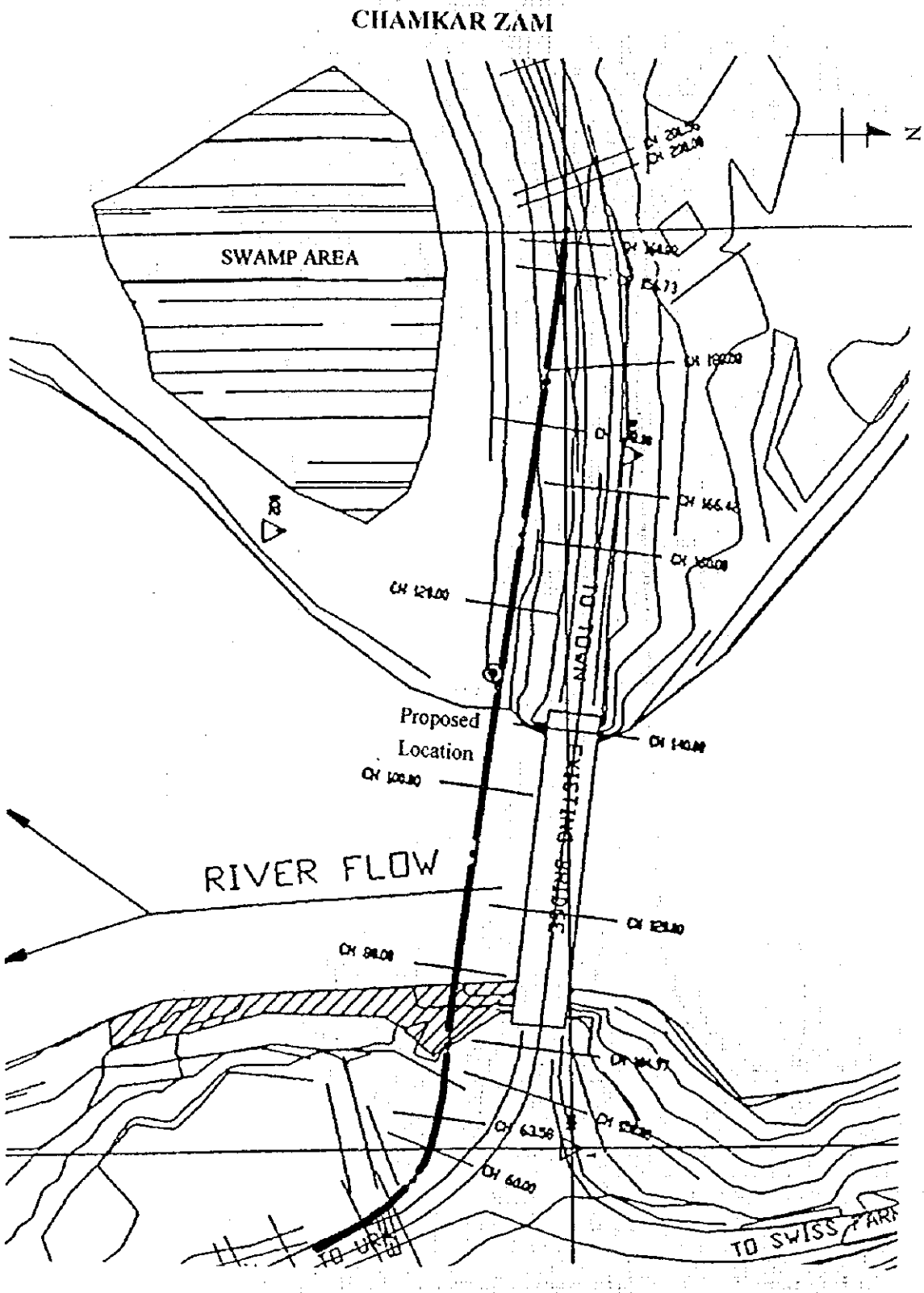


Figure 6.14 Plan of Alignment Alternatives for Bridge No. 2 Chamkar Zam

(Not to scale)

BJEE

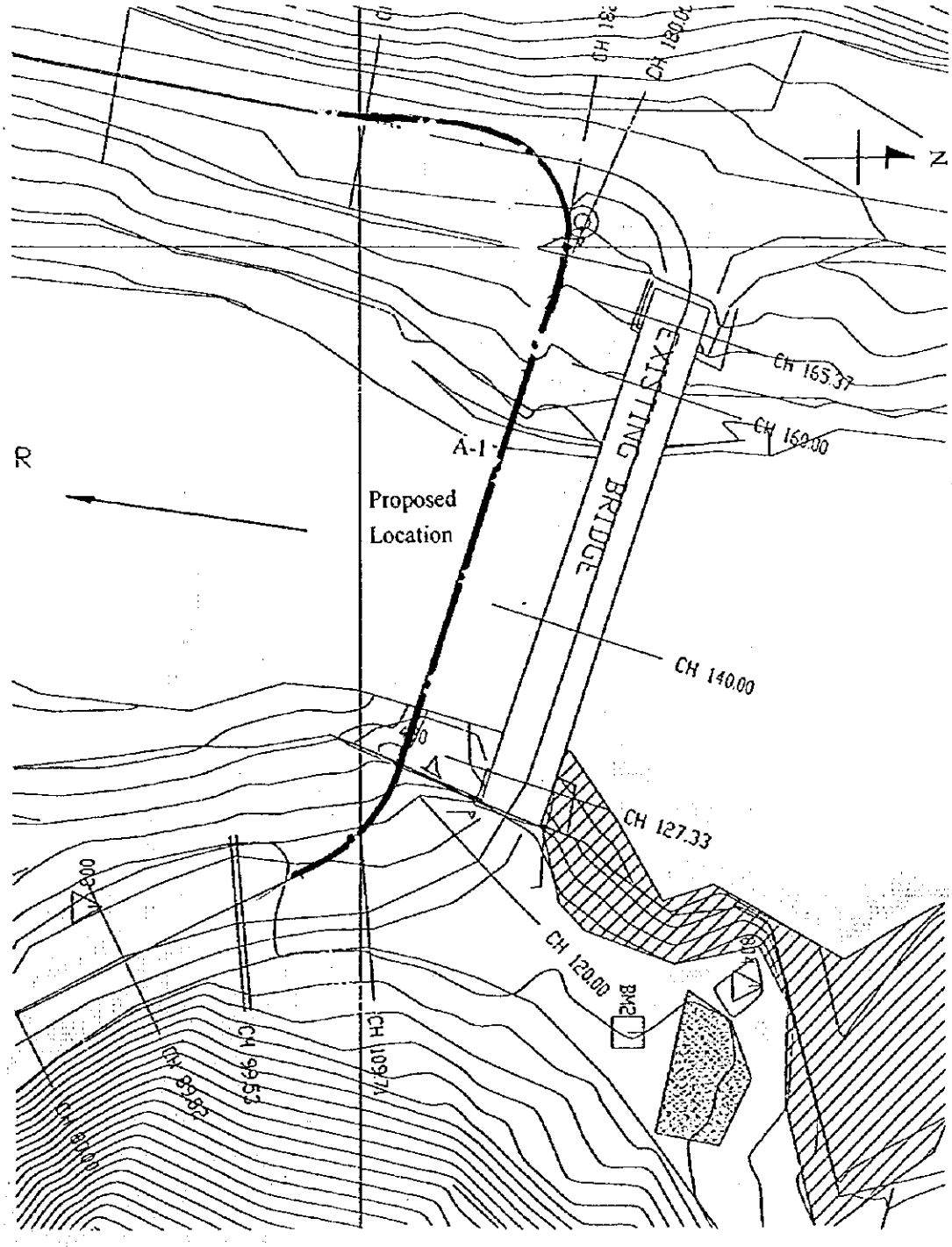


Figure 6.15 Plan of Alignment Alternatives for Bridge No. 3 Bjee

(Not to scale)

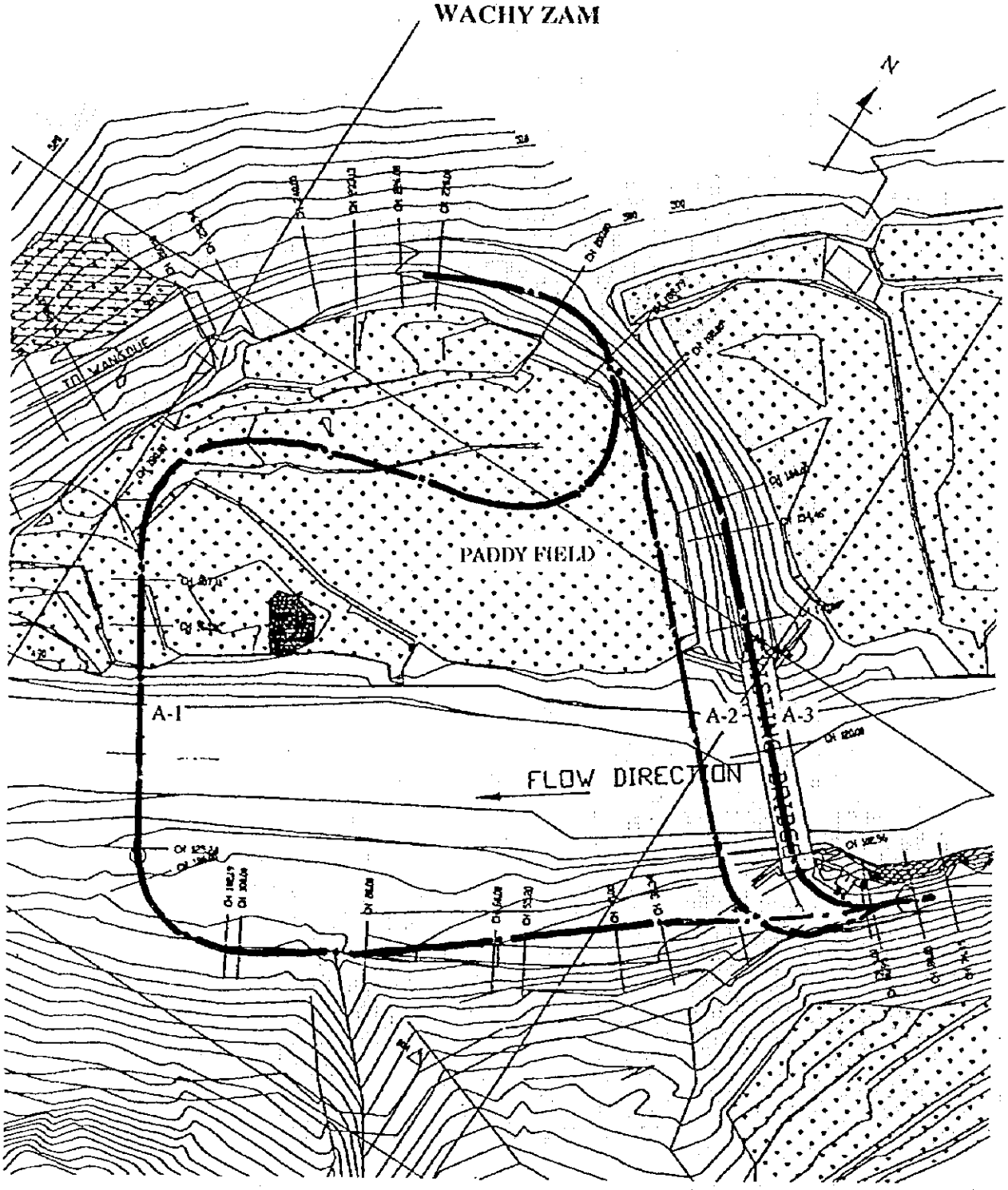


Figure 6.16 Plan of Alignment Alternatives for Bridge No. 4 Wachy Zam

(Not to scale)

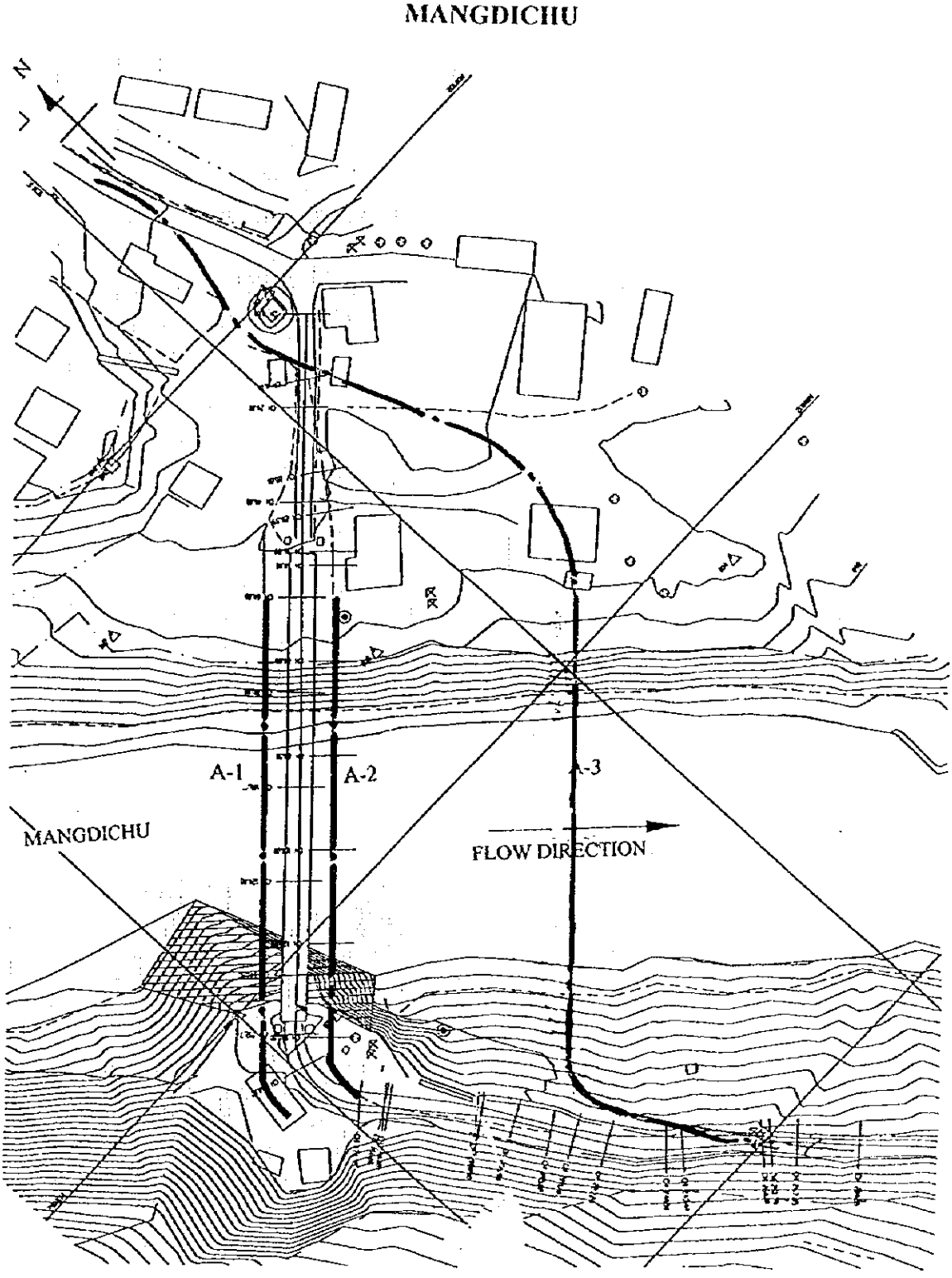


Figure 6.17 Plan of Alignment Alternatives for Bridge No. 5 Mangdichu

(Not to scale)

6.6 Evaluation of Alternatives

Comparison of alternatives and results of evaluation are summarized as shown in Table 6.16.

Table 6.16 Comparison of Alternatives and Results of Evaluation

Bridge No.	Bridge Width	Bridge Length	Bridge type (Superstructure)	Evaluation	Bridge Alignment	Evaluation
1	5.5 m	54 m	Plate Girder	X	Alternative 1	O
			Truss	X	2	X
			Truss (Pony)	O	3	X
2	7.5 m	43 m	Plate Girder	X	No Alternative	
			Truss	X		
			Truss (Pony)	O		
3	5.5 m	50 m	Plate Girder	X	No Alternative	
			Truss	X		
			Truss (Pony)	O		
4	5.5 m	43 m	Plate Girder	X	Alternative 1	O
			Truss	X	2	X
			Truss (Pony)	O	3	X
5	5.5 m	100 m	Langer	X	Alternative 1	X
			Lohse	O	2	X
					3	O