Paro Dzongkhag is now carrying out rehabilitation work on the road which is to be extended in the future and connected with the farm road which has been requested to be extended through the Japanese grant aid.

4.3.4 Outline of Facilities and Equipment

(1) Outline of Facilities

1) Irrigation Facilities

Irrigation channels to be rehabilitated are as follows:

Channel	Distance (m)	Command Area (ha)
Chendo Chukha	2,991	48.0
Bamdoley	1,904	40.0
Rema Thangyul	837	24.2
Sharimochu	1,230	24.0
Gangyul	2,547	21.6
Shaba Shengo	1,906	10.1
Tshetey Yuwa	867	19.6
Shaba Bara	2,240	18.2
Dujey Dingkha	1,672	28.2
Serekha	1,398	32.0

(2) Farm Roads

All of the farm roads are to be newly constructed as follows:

Farm Road	Distance (km)	Area to Benefit (ha)	No. of Farm Houses
Site 1: Dotey (Left side of Dotey River)	1.4	172	72
Site 2: Bamdoley - Jangsa (Jangsa Bridge)	6.2	116	95
Site 3: Satsam Chorten - Tshongdu	8.6	310	174
Site 4: Nyemizam - Khangku	1.7	43	38
Site 6: Bondey - Gyebjana	1.7	50	20
Site 7: Chorten - Sarpa - Deankha	3.4	50	32

3) River Protection

River protection work is proposed to be executed at the following sites:

Route	Distance (km)	Remarks
Site 1: Dotey River	1.4	Both sides of farm road extension
Site 2: Bamdoley - Jangsa (Jangsa Bridge)	6.2	Left bank of Paro
Site 4: Nyemizam - Khangku	1.7	Left bank of Paro
Site 5: Gyebjana Rongchu	2.05	Right bank of Gyebjana Rongchu
Site 7: Chorten - Sarpa - Deankha	3.4	Left bank of Paro

4) Reconstruction of the Jangsa Bridge

a) Type
- Total length : 100 m
- Span number : 5 spans
- Substructure : RC structure (Open foundation)
  Number of piers = 4
  Number of abutments = 2
- Superstructure : Steel-H-shaped girder (Simple beam)

b) Accessory Work
- Riverbed protection and rehabilitation of banks
- Protection of piers
- Realignment of an irrigation channel
- Access roads
- Demolition of the existing bridge

(2) Outline of Equipment

Construction equipment and the plant to be procured are planned as follows:

Equipment	Capacity	Nos.	Use
- Bulldozer	21 ton	1	Carrying soil
- "	15 ton	1	" "
- Motor grader (Blade: 2.6m)	86 ps	1	Leveling work
- Backhoe	0.6 m^3	1	Soil excavation
- "	0.35 m^3	1	" "
- Dump truck	11 ton	5	Transportation
- Mixer truck	2.2 m^3	2	Concrete
- Vibrating roller	10 ton	1	Compaction
- Wheel loader	1.2 m^3	1	Carrying in plant
- Pick-up	4 WD	1	Staff transportation
- High pressure washer		1	Equipment washing
- Crushing plant		1	Crushed stones
- Spare parts, including for equipment procured		1 set	

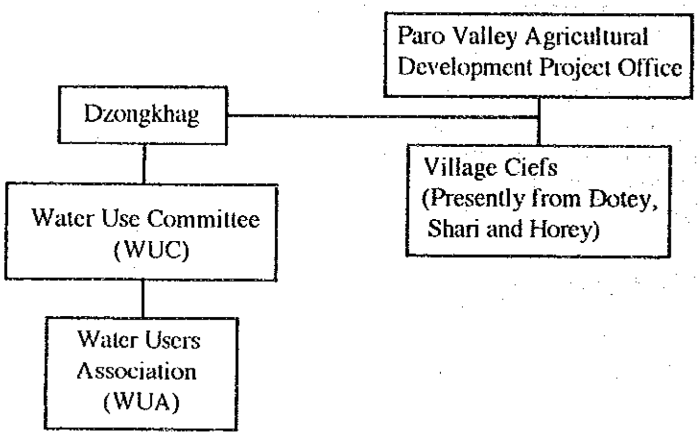
4.3.5 Maintenance Plan

(1) Maintenance System

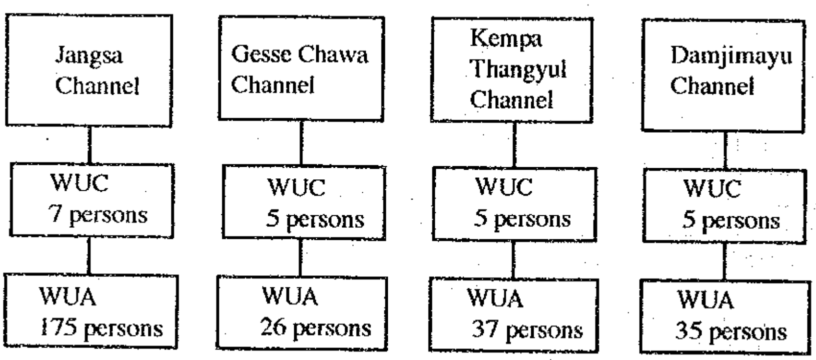
The basic plan for maintenance was agreed upon at a meeting with the agencies concerned, as recorded in the Minutes of Discussions.

1) Irrigation Facilities

During the past implementation period of Stage 1.2, on 11 December 1991, Water Users Associations (WUA) were organized for the maintenance of irrigation channels and for water use and water management, under the direction of Dzongkhag and PVAD. This is shown below:



The composition of WUC and WUA in Stage 1.2 was as below:



Associations such as those above are to be organized in each stage and are to maintain irrigation facilities and manage water use.

2) Roads

The maintenance bodies for roads are:

- *New Jangsa Bridge* : Dzongkhag
- Farm roads : Dzongkhag

3) River Protection

The maintenance of the river protection work is to be done by the Dzongkhag.

(2) Method of Operation and Maintenance

1) Irrigation Facilities

The operation of the irrigation facilities is to be done through the Water Users Association (WUA), under the direction of the Water Use Committee (WUC) which is to be organized for each irrigation channel and to hold regular meetings, taking assistance from the Dzongkhag's irrigation engineers. Ordinary maintenance work is: weeding, cutting of trees and removal of sediments from channels and grit chambers. *These jobs shall be carried out twice a year, before and after the* rainy season. Minor repair work shall be carried out from time to time, under the direction of the WUC. Manpower for this work shall be provided by the WUA. The total cost for the above minor repair is estimated at Nu. 57,000 (2,000 Nu./km/year), and the major materials required are U-shaped and L-shaped concrete blocks, cement and gabions. They are to be provided and stored by the WUA. Large repairs shall be carried out by the Dzongkhag.

2) Farm Roads and River Protection

The routine maintenance work is to be done by the Dzongkhag at a cost of Nu. 144,000 (5,000 Nu./km/year). The main materials required are *crushed stones to be supplied by the crushing plant and gabions. The* necessary equipment consists of backhoes, dump trucks, and motor graders.

3) Jangsa Bridge

The superstructure of the bridge is made of anti-weather type steel girders, making it maintenance free. Accordingly, the ordinary maintenance work is on the road only, with a total cost of Nu. 21,000 (210,000 Nu./km/year). In the case of lighting facilities being installed by the Bhutanese, the electricity cost would be additional.

4) Construction Equipment

The repair costs for the equipment to be supplied by the project will be as below:

Equipment	Annual Repair Cost (Nu. x1,000)	Rate of Repair Cost (% /year)
- Major construction equipment (Bulldozer, backhoe, etc.)	2,830	7
- Other construction equipment (Small backhoe, wheel loader, vibrating roller, crane, grader, etc.)	690	5
- Major transportation equipment (Dump truck)	1,640	10
- Other transportation equipment (truck mixer, self-loading truck, truck with crane, etc.)	330	7
	Total	5,490

This equipment has life spans which vary according to the size of the machinery: 4 years for small pieces, 5 years for middle-sized pieces, and 6 years for large ones is standard. The life span of transportation equipment is a bit shorter than that of construction equipment. Although being subject to the maintenance given, new equipment is generally necessary after the above time periods. However, in this project, spare parts are planned to be supplied in the form of assembled units in order to get longer use from the equipment. The repair costs are to be paid through the rental fees.

v) Plant

The annual repair costs of the plants are estimated at about 7 %/year for the plants: thus, the total annual repair cost for the plants will be Nu. 800,000. This cost will be financed by the proceeds from products.

4.4 Technical Cooperation

Training for the plant engineers is planned to be done by a Japanese instructor, prior to the commencement of Stage 1.3. His assignment is to check the operating conditions of the plant and to train Bhutanese personnel. The time allowed will be 2 weeks for the crushing plant, 2 weeks for the concrete plant and 1 month for the batching plant.

As for the training of an equipment operator, his training on transportation equipment is recommended to be carried out in Japan. The time allotted will be around 2-3 months.

The training of a bridge engineer will take 2-3 months in Japan, and on-the-job training during the next stage is considered as an additional chance.

Chapter 5. BASIC DESIGN

5.1 Integrated Agricultural Development

5.1.1 Irrigation Facilities

(1) Design Policy

1) Basic Policy

Initially, the system of irrigation channels is to be examined. The channels need to be able to perform their necessary functions. Water management shall be carried out in order to meet the local demand. The following items, therefore, shall be considered.

- Stabilization of water intake
- Discharge capacity
- Diversion, confluence, and control of channel water
- Stabilization of irrigation channels
- Water management
- Economic efficiency of repair and operation costs
- Conservation of the environment

2) Irrigation Channels Design Policy

i) Intake Facility

At the proposed sites for the channel intakes, the present longitudinal riverbed gradients are 1/80 - 1/200 in the Paro and Dotey Rivers. Their tributaries, on the other hand, the Ron, Ri, and Gebiolumi have much steeper gradients of about 1/10. The riverbed is made of boulders with diameters of 30-50 cm on the average, and sometimes reaching a maximum of 2 m. The Paro and Dotey water courses are unstable in particular at their middle reaches and thereafter. The water routes are thought to change every year due to flooding and sedimentation. Basically, it appears that subsidence of the riverbeds is occurring. Accordingly, alternations in the intake facilities are to consist of a) prevention of riverbed subsidence and stabilization of intake water level by the construction of a low-height diversion weir made of concrete and mattress work, b) stabilization of the

waterway with groins, and c) securing the intake facilities with revetment work around each facility.
In general, taller diversion weirs preferable when one considers the incoming earth and sand. In this project, however, it is planned that the weirs be as short as possible considering the soil sedimentation upstream of the weir, the drainage capability due to the backwater close to the weir, and the fish (mainly brown trout) going upriver. Incoming earth and soil will be removed by constructing settling basins for sand or gates for drainage in the waterways.

ii) Channel Works

The channel works in the project consist of of open channels made of wet masonry, earth, steel plates, conduits, water bridges, siphon works, drops, chutes, etc.

Present problems with the existing channel works are:

a) Many channels are made of earth; and most of the channels have irregular cross-sections and variable longitudinal gradients at several points.

b) Where open channels pass through mountains, there has been considerable channel-collapse, and a great deal of sediment has built up in the channel due to slope erosion.

c) To solve the above problem, an alteration of the channel route is almost impossible as it would result in the enlargement of the slopes.

d) Open channels installed along the rivers easily slip down due to river bank erosion.

e) There is a great deal of sediment in the channels due to a lack of settling basins and/or drainage facilities.

As a result, the channel work will involve i) modification of cross-sections in places where the present area is insufficient, ii) modification of longitudinal gradients, and iii) improvement and strengthening of river revetments.

iii) Diversion, Regulation and Confluence Facilities

Most of the present diversion facilities merely consist of openings in channel walls, and there are practically no gates, in particular regulating gates for controlling water levels. Water levels have been controlled by putting stones into the channels.

To make openings in the channel walls for diversion points without proper planning could result in uneven distribution. In particular, an excess distribution upstream would cause a water shortage downstream. Therefore, permanent facilities made of concrete of wet masonry are planned for channels which have many upstream diversion points. The regulating gate to maintain water levels will be made of wooden stop-logs, taking future replacement costs into consideration.

Crossing will be done by means of confluence facilities, taking into consideration the most effective use of the discharge of the stream, although there are the alternatives of the underpass and over-shoot methods.

4) Protection Facilities

As mentioned above in item 2, the slope protection work and additional construction of settling basins and drainage gates are necessary for the proper management of the channels. They will be constructed in order to facilitate operation and maintenance.

5) Maintenance Facilities

In this project, wooden stop-logs will be installed at water intake points to stop the flow of water for cleaning and other maintenance, although it will be necessary to construct maintenance roads and install screens in the future. Construction of maintenance roads is not proposed in this project.

(2) Study of Design Conditions

1) Hydraulic Conditions

a) Design Discharge

The sizes of facilities are to be, in principle, determined based on the maximum design discharge. However, facilities for confluence and overflow should also be considered to deal with intake water irregularities. The maximum design discharge of the channels is to be based on the product of the required amount of water for paddy fields, 4.73 lit/sec/ha, and the command areas. The maximum design discharge for each channel is given in Table 5.1. (For more detail, refer to the Appendix 11.)

Table 5.1 Maximum Design Discharge

Name of Channel	Command Area (ha)	Maximum Design Discharge (*) (m^3/sec)
Shaba Shengo	10.11	0.048
Shaba Bara	18.20	0.086
Dujey Dingkha	28.20	0.133
Serekha	32.00	0.151
Tshetey Yuwa	18.51	0.088
Sharimochu	24.00	0.114
Gangyul	21.60	0.102
Chendo Chukha	48.00	0.227
Bamdoley	40.00	0.189
Rama Tangyul	24.20	0.114

(Note) : (*) Based on the water requirement of 4.73 lit/sec/ha

b) Permissible Velocity

i) The minimum permissible velocity:
- Open or Earth channels : More than 0.7 m/sec, to prevent settling and plants from growing
- Concrete or steel channels : More than 0.5 m/sec
- Box culverts : 1.3 times open channels
- Siphons : 1.5 times open channels

ii) The maximum permissible velocity:
- Earth channels (consisting of sandy clay) : 1.2 m/sec
- Channels made of wet masonry or concrete : 3.0 m/sec
- Precast concrete flumes : 1.5 m/sec
- Steel-corrugated flumes : 3.0 m/sec

c) Hydraulic Design

i) Hydraulic Formula

The Manning Formula will be used for the calculation of design discharge and the dimensions of open channels, and the Hazen Williams Formula for the pipeline planning.

ii) Roughness Coefficient

The roughness coefficient is to be defined for the types of material and other conditions of the channel as follows. For the project, maximum values of the coefficient are employed, considering that channels have considerable meandering and will have said deposit.

Table 5.2 Roughness Coefficient of Channels

Channel Material and Condition	Coefficient
Concrete and wet masonry	0.016
Concrete (Precast flume)	0.016
Steel plates (Smooth surface painted)	0.017
Steel plates (Corrugated surface)	0.030
Earth (with some weeds)	0.033

iii) Loss of Head

In the hydraulic calculation, as a general rule, losses caused by a) friction, b) inlet and outlet, c) change in cross-section, and d) screen are to be considered.

iv) Freeboard

In general, freeboards are determined considering a) the change in the roughness coefficient due to the age and accuracy of the work, b) the change of dynamic head into static head, and c) the height of waves caused by wind. In the project, the following freeboards are employed.

Height of channel (mm)	300-450	500	600-1,300
Freeboard (mm)	50	100	150

2) Structural Conditions

As no design standards exist in Bhutan, structural conditions such as loads, foundations, climatic conditions, etc., will be based upon the "Design Standards for Land Improvement Projects (Water Canals No.1), 1986" established by the Agricultural Structure Improvement Bureau, the Ministry of Agriculture, Forestries and Fisheries, Japan, taking local work conditions and economical efficiency into account.

1) Loads

Various loads such as dead load, live load, water pressure, buoyancy or uplift, earth pressure, truck load, dynamic load, and crowd load will be
considered, according to the type of structure, materials to be used, structure sites, work conditions, material transportation situation, environmental conditions, etc.

a) Dead Loads

The following unit weights will be used for the calculation of dead loads:

Table 5.3 Unit Weight

Materials	Unit Weight (ton/m^3)
Steel	7.85
Reinforced concrete	2.50
Plain concrete	2.35
Water concrete	1.00
Earth	1.80

b) Earth Pressure

In principle, Ranking's Formula will be used.

c) Truck Load and Dynamic Load

- Truck load : 14 ton truck at the intersections of farm roads, and 9 ton tractor at other places.
- Dynamic Load :

Earth covering (m)	Less than 1.5	1.5-2.5	Above 2.5
Coefficient of impact	0.4	0.3	0.2

d) Uniform Load

The uniform load is set as 300 kg/m^2, and it is assumed that the uniform load would not occur simultaneously with truck load.

(3) Basic Design

A basic design of 10 irrigation channels was carried out based on the survey results. The outline of the 10 channels is describbd below, and the location of the channels is shown in Fig. 5.1.

1) Chendo Chukha Channel

a) Intake Facility

As the channel water level is +2,348.77 m at the intake site, the river water level must be +2,348.80 m. In the dry season, the river water level at this point is +2,348.3 m to + 2,348.4 m, so the water level should be raised by 50 cm by means of a backwater created by a weir. The height of the weir is to be 1.8 m. Considering the height of the weir and the conditions of the Paro River at this point, viz., the riverbed is composed of boulders and cobblestones which are more than 50 cm in size, the weir should be strong and made of concrete, rather than a simple wooden mattress. Since the height of the weir is comparatively height, it is to be equipped with a fish-way.

b) Channel

The channel is made of wet masonry in the span between Points No.15+8.0 and No.25+1.0, and of earth in other spans with the exception of strategic points where the channel is made of wet masonry. The plant of the reform of the main spans is as follows:

The span between the starting point and Point No.2+10.0 has gentle gradients like natural slopes. That permits a slow inlet velocity, which is convenient for the prevention of grit coming in. As the left bank of the span has steep slope sides, ideally, the channel route should approach from the right side. Thus, this span shall be made of precast concrete flumes (L-600x300), with a channel gradient of 1/400.

The span between Points No.2+10.0 and No.7+0.0, having a steep gradient of 1/24, is planned to be of concrete, since an earth channel is unsuitable from the viewpoint of erosion and the drop work for the slope-adjustment is inferior in terms of grit sediment and construction cost. Here, the cross section of the channel is planned to be same as that upstream, and larger freeboards will be necessary.

In the span between Points No.7+0.0 and No.15+9.0 there exist a partial flume, an overflow, a one-side channel wall, and pedestrian bridges. Some parts are occasionally flooded by water coming from upper side-slopes where no protection work has done. Further along this span, there are steep slopes on the left bank and the Paro River is located near the right bank, making space narrow and land unstable. Thus, this span is also planned to be reconstructed with precast concrete flumes (L-600x300). Its gradient is designed as 1/250.

The span between Points No.15+8.0 and No.25+1.0 is of wet masonry as described before, and has 2 points where slope protection has been done and a repaired site.

Other spans, Points No.25+1.0 to No.90+0.0 (channel-bed gradient : I=1/250), Points No.90+0.0 to No.120+0.0 (I=1/90), and Points No.120+0.0 to the terminal No.149+10.7 (approx. I=1/55) are planned to be an earth channel, as are parts having insufficient or irregular cross-sectional areas.

c) Diversion, and Control and Confluence Facilities

i) Diversion Facilities

The channels has 47 diversion facilities for irrigation and one for another purpose. Most of the facilities are made of wet masonry, and there has been no serious damage to them, although some are partially broken. It is believed that they will be maintained and repaired by the beneficiaries of their functions and so they will not be part of the project.

ii) Control Facility

It is proposed that a spillway be constructed at Point No.7+0.0, since the intake weir there is of a fixed-weir type and excess intake is feared due to drop-down likely to be caused by steep gradients near the intake. The spillway will have dual functions by serving as a stilling basin and settling basin.

iii) Confluence Facilities

There are two confluence points along the channel. One is the existing structure, made of wet masonry, which functions as a distribution facility, and the other is that described in the preceding section.

iv) Protection Facility

Protection facilities required in this channel are a) slope protection work on the left bank in the spans between Points No.12+0.0 and No.13+17.0, Points No.18+5.0 and No.18+13.0, and Points No.19+8.8 and No.19+13.6; b) river revetment work on the Paro River in the span between Points No.13+0.0 and No.15+0.0; and c) crossing drainage work at Point No.140+5.0. They are proposed to be worked into the project taking the safety of the channel into account.

2) Bamdoley Channel

a) Intake Facility

Based on a water level of +2,353.18 m at the starting point of the channel, the river water level needs to be above +2,353.28 m. As the water level of the river in the dry season is +2,352.2 m - +2,352.0 m, the water level has to be raised by 100 cm by means of a weir to be additionally constructed. The weir will be made of cobblestones and boulders. Water depth at this point of the Paro River exceeds three meters, even in the dry season, hence the height of the weir is to be above four meters. Around the site, rolling rocks of 2-3 m are commonly seen, and deeper depths continue 300 m downstream. If the weir merely planned for irrigation intake, a fixed- weir type concrete weir would be considered. However, taking into account the difficulty of construction, which involves temporary construction, construction costs and protection of fish, a weir made of concrete would not be effective. Consequently, the weir is planned to be made of stone masonry work.

b) Channel

The existing channel is made of wet masonry in the span between the starting point and Point No.38+0.0, and of earth in most of the remaining parts. The rehabilitation plan is described as follows:

In the wet masonry span, from the starting point to Point No.38+0.0, the longitudinal gradient is almost constant. The cross section can be classified into five spans. Hydraulic calculations showed that sections below Point No.2+0.0 are insufficient. Located at a narrow points, this span should be rehabilitated with L-shaped concrete flumes (L-600x300). The gradient is planned to be 1/800, a little steeper than that of the present one, in order to minimize excavation volume.

Also in the span between Points No.38+0.0 and No.53+0.0, the cross section is insufficient. This span will be rehabilitated as an earth channel having a cross-section of 600 mm bottom width x 600 mm height, a slope of 1:1, and a channel gradient of 1/800.

The span between Points No.53+0.0 and the terminal point has steeper gradients and inverse gradients at many points. The rehabilitation will be carried out partially to create a gradient of 1/80 so as to keep the flow velocity within permissible levels.

c) Diversion and, Regulation and Confluence Facilities

i) Diversion Facilities

The channel has nine diversion facilities for irrigation. Most of them merely consist of openings in the earth wall and have almost all deteriorated. They are to be rehabilitated together with the channel rehabilitation work.

ii) Regulation Facilities

There is an overflow weir which acts as a regulation facility at Point No.18+16.0. It is planned to be rehabilitated as a settling basin, together with the channel rehabilitation work.

iii) Confluence Facility

The channel crosses a valley stream at Point No.34+15.0. The possibility of the entire flow of the valley stream pouring into the channel, in times of flooding, is a risk for the channel, as the valley has a wide area of 4.5 km^2. Accordingly, the confluence facility will be planned so that the ordinary flow of the stream can enter the channel, but in case of flooding, it will bypass the channel via a grade separation.

d) Protection Facility

There exist seven blow-offs for operational purposes, one of which has a settling basin. Four of them were constructed by beneficiaries. Some are installed in orchards. All of them will be rehabilitated in the project.

Slope protection work will be required in five spans, totaling 55.5 m in length.

3) Rema Tangyul Channel

a) Intake Facilities

As the present structure permits the intake of water, the construction of a weir for intake purpose will not be considered. The Paro River' velocity at the channel intake is changeable due to the riverbed. It is, therefore, not expected to be possible to take in water at a steady rate utilizing rigid structures which would require higher construction costs. In the project, the present facility, formed of cobblestones on the riverbed, is planned to be replaced with gabions.

b) Channel

In addition to the intake point, a span between the starting point and Point No.7+10.0 of the present channel is made of cobblestones. It will be replaced by a gabion wall for the same reason as that of the intake facility. The left bank of the channel is a slope which has been eroded by the river and which has collapsed in some places. The channel wall on the slope side is therefore scheduled to be rehabilitated with gabions which will have the additional role of protecting the wall.

The span between No.7+10.0 and the end of the channel will not be rehabilitated, with the exception of drop work at Point No.41+10.0.

d) Diversion and Confluence Facilities

i) Diversion Facilities

In the channel there are four diversion facilities, all openings in the earth channel wall. Although they are in poor condition, rehabilitation work is to be left to the beneficiaries, since the work is not all that heavy.

ii) Confluence Facilities

The channel is crossed by two small streams at Point No.13+10.0 and No.40+5.0. These points will be treated in addition to the diversion facilities, since the catchment area of the stream is very small.

d) Protection Facilities

Three sites, totaling 75.0 m in length in the span between Points No.7+10.0 and No.14+0.0, need slope rehabilitation and will be repaired with gabions.

4) Shaba Shengo Channel

a) Intake Facility

Judging from a water level of +2,208.75 m at the starting point of the channel, the water level of the river needs to be +2,208.85 m. As the river water level in the dry season is around +2,207.6 m, the height of the weir required will be 1.15 m. It will be made of a five-stepped wooden mattress. A collapsed span, which makes up a 3 m length of the present intake facility, is to be rehabilitated.

b) Channel

The channel includes many spans made of wet masonry, totaling 720.1 m in length. There are three major spans (Points No.0+0.0 to No.12+10.0, Points No.32+3.8 to No.35+17.8, and Points No.47+15.0 to No.66+ 1.0) and four other minor spans. In the planning of the channel rehabilitation, spans made of earth, other than the above masonry spans, will be so designed that the wet masonry will not be changed. The spans to be rehabilitated are as follows:

The span between Points No.12+19.4 and No.16+8.6 will be replaced with concrete L-shaped flumes (L-600x300). Thus, the backwater caused at Point No.17 will not stretch back as far as Point No.15.

In addition to the above, the span between Points No.16+18.2 and No.17+9.2 is to be replaced with concrete L-shaped flumes (L-600x300) having smooth wall surfaces.

The span between Points No.20+7.8 and No.32+3.6 is insufficient in cross-sectional area and passes through the foot of a mountain. This span will also be replaced with concrete L-shaped flumes (L-600x300) which are structurally strong.

The span between Points No.67+2.0 and No. 82+0.0 has an irregular longitudinal gradient and will be rehabilitated with earth.

The span between Points No.82+0.0 and No.88+0.0 is a steep slope.

The span will be rehabilitated with concrete U-shaped flumes (U-300) in order to avoid channel body erosion.

c) Diversion and Confluence Facilities

i) Diversion Facilities

There are 25 diversion facilities for irrigation purposes located along the channel. They are to be rehabilitated together with the channel rehabilitation work.

ii) Confluence Facility

The channel has an inlet at Point No.2+9.7, which was made by knocking down a small part of the channel wall. Water from the inlet comes from a small paddy field of about 0.1 ha and will not damage the channel. The inlet will merely be renovated.

d) Protection Facility

There is an existing settling basin from Points No.12+10.0 to No.12+19.4. It can be rehabilitated easily by the beneficiaries with minor work and will not be included as part of the project.

5) Gangyul Channel

a) Intake Facility

The Sharirong River, a tributary of the Dotey River, is the channel's water source. Based on a water level of +2,407.35 m at the starting point of the channel, the river water level required is +2,407.45 m. The height of the present cobblestone weir is 1.75 m. The weir is planned to be reconstructed using concrete, since the weir is tall and the river is rapid. The right bank of the weir has collapsed on the side-slope for about 25 m. The collapse is recent and continuing. The soil is clayey and mixed with stones. To prevent this collapse, it would be necessary to relocate the weir upstream and to take water from the left bank side. However, this would require the additional work of water transmission from the left bank to the right bank, an increase of construction costs, and, in addition, it would cause environmental disruption due to the tree cutting associated with the construction work. In conclusion, the collapsed of the slope is planned to be repaired on the spot. It will be done by placing gabions at the foot of the slope and wooden pegs and willows trees on the slope, taking harmony with nature into consideration.

b) Channel

The entire channel passes through a sloping mountain flank and the longitudinal gradient of the channel is steep. Being made of earth, the channel has many sites which are eroded by water or deformed by grit inflow. The following are sites to be rehabilitated:

The span between Points No.0+0.0 and No.40+0.0 has a very steep gradient of 1/27 on the average and its flow velocity would not be within the allowable limits for an earth channel. Construction of drops would be difficult from the viewpoint of topography. Accordingly, the span is planned to be lined with concrete. The channel will be made of wet masonry, due to the difficulty of transportation of concrete flumes to the site.

The span between Points No.40+4.0 and No.65+13.0 is planned to be rehabilitated with an earth channel having a 1/42 gradient in order to lessen the steep gradient at Point No.57.

The span between Points No.65+13.0 and No.85+0.0 is in poor condition, particularly the upstream part. The span is planned to be rehabilitated with an earth channel having a gradient of 1/55.

The span between Points No.85+0.0 and No.87+5.0 will be rehabilitated with wet masonry, since the span has a steep longitudinal gradient of 1/10.

The span between Points No.98+0.0 and No.126+0.0 will be rehabilitated with an earth channel so that whole span will have a constant gradient and the steep gradient in the part between Points No.107+14.0 and No.110+10.0 will be improved.

c) Diversion and Confluence Facilities

i) Diversion Facilities

There are 14 diversion facilities for irrigation purposes and two for domestic water supply. They are to be rehabilitated together with the channel rehabilitation work.

ii) Confluence Facility

There is a confluence with a small stream at Point No.111+14.7 in the channel. The water is safely fed into the channel and is to be utilized as an effective water source.

d) Protection Facility

There are no settling basins in the channel. A settling basin with a spillway is planned to be constructed at Points No.0+0.0 to No.1+0.0.

6) Tshetey Yuwa Channel

a) Intake Facility

At present, the Paro River near the intake of the channel has the following particular conditions: a) river revetment work, continuing from the airport, has already been done to a point 110 m upstream of the intake; b) at the end point of the river revetment, a drainage ditch crosses a road; c) on the right bank, the Woochu River enters the Paro River 20 m downstream of the intake, and around that point the maximum water depth is about 4 meters; d) there is a sand pile with a thickness of 1.4 m and 80 m width on the right bank; and e) there is an old river course with 2 m depth and 13 m width on the right abutment.

The necessary water level for water intake is +2,220.37 m at the present intake site, and the river water level in the dry season is +2,219.1 m, while the riverbed is +2,218.3 m. Accordingly, the height of the weir needs to be 1.57 m. This height cannot be maintained by a wooden mattress type weir, but can be by a concrete weir. However, it is not desirable to construct a weir at this site because the weir foundation would not be securely constructed due to the reason mentioned above in (c). Hence, it shall be relocated, preferably 60 m upstream of the present intake point, considering the above conditions (a) and (c). The other conditions, (b), (d), and (e) will not affect the relocation of the weir. The necessary water level for water intake at the new location is +2,220.52 m, and the river water level in the dry season is +2,219.9 m, while the riverbed is +2,219.1 m. Accordingly, the height of the weir needs to be 0.92 m. The height will be maintained by a four-stepped wooden mattress to be installed. In relocating the weir, stability will be improved and construction costs of the weir will be minimized. On the other hand, construction costs for extension work of the channel and river revetment will increase. However, overall the total cost will lessen.

b) *Channel*

The channel has gentle slopes throughout its length. There are wet masonry spans between points No.0+0.0 and No.12+6.5, between Points No.15+5.5 and No.18+16.2, and between Points No.31+9.8 and No.33+6.9. The cross section of the channel is sufficient for the design discharge throughout the whole length, although there is a somewhat disordered span between Points No.21+5.5 and No.29+15.4. The span between Points No.15+8.3 and No.20+9.1 passes along or under houses and under the national highway. The channel water is at one point discharged into a stream at Point No.20+9.1 and thereafter re-enters the channel at Point No.20+16.5. The re-entry systems has an advantage from the viewpoint of effective use of the water source, since the stream keeps flowing even in the dry season, although it is easily polluted by household waste. The span has been left out of the rehabilitation work.

The original plan of this channel aimed to transmit water to the area of farmland consolidation which was proposed in the previous basic design study. As the farmland consolidation work was excluded from the project, rehabilitation work of the irrigation channel which is located in the above area and was to be rehabilitated in the project is necessary. It means this channel should be extended to the terminal Point No.43+7.0.

In consideration of the above, the channel is scheduled to be rehabilitated with concrete L-shaped flumes (L-600x300) in the span from the starting point to 60 m. The river slope will be protected by gabions. The terminal span to be extended by 200 m will be rehabilitated with concrete U-shaped flumes (U-450).

c) Diversion and Discharge Facilities

i) Diversion Facilities

There is a diversion facilities at Point No.22+9.0. It is the sole diversion point to the farmland which benefits from it. It is possible to use the diversion point as it is; and rehabilitation work will not be planned for the distribution facility.

ii) Discharge Facilities

There is a discharge point at Point No.20+9.1. The discharge facility has no particular problems and will be used as it is.

d) Protection Facility (Re-entering Facility)

As the re-entry facility at Point No.20+16.5 connected with the settling basin is broken and its anti-sedimentation function is insufficient downstream, it is planned to be reconstructed.

7) Shaba Bara Channel

a) Intake Facility

Judging from a water level of +2,297.09 m at the starting point of the channel, the water level of the river needs to be +2,297.19 m. As the river water level in the dry season is around +2,296.8 m, the height of the required weir will be 0.70 m. It will be made of a four-stepped wooden mattress. Presently, the existing training levee of about 25 m in length leads river water to the intake site because the existing intake site is located at a place where the waterway approaches the right bank. Accordingly, in the project, the training levee is to be rehabilitated and a weir constructed 15 m upstream of the existing intake for more stable water intake.

b) Channel

As seen in the span between Points No.0+0.0 and No.3+0.0, the channel has many spans made of wet masonry located near distribution facilities. Most of them were constructed in 1988-89. The rehabilitation of the channel, therefore, will be done utilizing wet masonry spans as much as possible. The following are the main rehabilitation plans. The cross-sectional area upstream will have some allowance, since water shortage will probably occur.

The span between Points No.0+0.0 and No.1+7.0 will follow the same route as the proposed farm road and be newly constructed with concrete L-shaped flumes (L-600x300).

The span between Points No.1+7.0 and No.3+0.0 will be rehabilitated at broken points, since the span is made of wet masonry and has sectional area for the design flow.

The span between Points No.3+0.0 and No.21+14.3 also has an adequate cross-sectional area, but the middle of the span, between points No.11 and No.17, has a lower slope and the water level upstream of Point No.4+8.5 is not stable. Thus, the span will be rehabilitated with concrete L-shaped flumes (L-600x300).

The span between Points No.21+14.3 and No.24+12.6 has a steep slope. The span between Points No.21+14.3 and No.23+2.6 is made of wet masonry and will be used in the future as it is. The remaining span is made of earth and so erosion occurs; hence, it will be rehabilitated with concrete L-shaped flumes (L-600x300).

The span between Points No.24+12.6 and No.44+0.0 is made of earth and the span between Points No.24+12.6 and No.31+0.0 has undulations in its slope. The remaining span has an insufficient cross-sectional area. As the above matters are not very serious, the span is planned to be repaired with earth.

The span between Points No.44+0.0 and No.46+0.0 is for rapid flow and will be rehabilitated with concrete U-shaped flumes (U-450).

In the span between Points No.46+0.0 and No.89+0.0, the portion from Point No.80+0.0 and beyond will be repaired with earth, since the span has an insufficient flow capacity.

The span between Points No.89+0.0 and No.112+0.0 has sufficient discharge capacity.

c) Diversion Facilities

There is a large number of diversion facilities, at 98 locations in the channel. All of them are for diversion to small paddy fields. Unless proper water management is done, there will be water shortages. In the project, water stoppers will be installed on diversion facilities located in the channel spans to be rehabilitated in order to avoid water shortages in the downstream area and to improve water management.

d) Protection Facility

The channel has neither a settling basin nor a spillway. Construction of a spillway is considered difficult due to the long distance between the Paro River and the channel. In the project, the intake facility is designed so as to not take excessive water. A settling basin will be constructed around Points No.20+10.00.

8) Dujey Dingkha Channel

a) Intake Facility

Judging from a water level of +2,215.68 m at the starting point of the channel, the water level of the river needs to be +2,215.78 m. As the river water level in the dry season is around +2,215.2 m, the height of the required weir be 0.90 m. It will be made of a four-stepped wooden mattress. The steep slope on the right bank of the channel has collapsed, and is about 3 m in height and 20 m in length. The slope consists of sandy gravel with cobblestones and the slope length is 15-20 m, with slope angles of 50-70 degrees; thus, to completely control the collapsing is difficult. Soil erosion at the intake site will increase the entry of silt into the channel, making maintenance difficult, and so it is to be rehabilitated. In the project, taking harmony with nature and low construction costs into consideration, the use of gabions, and wooden pegs and the planting of willows on the side slope are planned as means of rehabilitation.

b) Channel

The channel consists of a wet masonry span between the starting point and Points No.24+9.0 and an earth channel span from Point No.24+9.0 and beyond. The wet masonry span is in parallel with the above mentioned steep slope. Main spans to be rehabilitated are as follows:

In the span between Points No.24+9.0 and No.28+0.0, the span from the staring point to Point No.25+16.0 does not maintain the original channel gradient due to soil sedimentation, and the remaining span has steep slopes. The whole span, therefore, will be rehabilitated with earth to improve the sectional area and slope gradient.

In the span between Points No.52+9.0 and No.77+17.0, the span between Points No.52+9.0 and No.59+0.0 and the span between Points No.69+0.0 and No.77+17.0 are planned to be rehabilitated with cut-banking earthwork.

The span between Points No.77+17.0 and No.83+14.0 has a steep long-slope part, and work for longitudinal gradient adjustment will be done. It will be rehabilitated with concrete U-shaped flumes (U-300), since the span is to be a banking channel and the flow velocity will reach the maximum for an earth channel, which would cause erosion.

c) Diversion and Regulation Facilities

i) Diversion Facilities

There are 30 diversion facilities in the channel. All of them are simple openings in the earth walls. Those which are included in the proposed channel rehabilitation work for the span are to be rehabilitated together with the channel. Other are to be consolidated by the beneficiaries of the channel.

ii) Regulation Facility

The present channel is not outfitted with a settling basin or a spillway. But considering sedimentation in the channel at present, construction of such facilities is necessary. They will be located around Point No.27, since land acquisition at or near the starting point is difficult.

d) Protection Facility

The steep slope, as mentioned in the intake facility, continuous in the span between Points No.0 and No.24. Along this slope, the span between Points No.0+0.0 and No.4+0.0 and the span between Points No.7+0.0 and No.8+0.0, where land erosion has already occurred or is feared, will be protected with slope protection work. The method will be the same as that of the intake facility.

9) Serekha Channel

a) Intake Facility

The intake facility is on the Gebiolumi River. Due to the recent flood, the riverflow conditions at the original intake site have changed and it is difficult to secure the channel route at the intake. Fortunately, the command area of this irrigation channel is situated 10 m lower than the intake water level, and it has been decided to locate a new intake about 30 m downstream from the existing intake site. The river bank around the intake is quite eroded and riverbed deposited with sediment. Thus, in order to stabilize the water intake, the intake weir was planned with ample height. Judging from the required intake water level of +2,362.0 m, it has been decided that the crest elevation of the weir be +2,363.0 m and the weir height be 3.0 m. The weir is planned to have a blow-off equipped with a fish way.

b) Channel

The longitudinal gradient of the channel is about 1/20. About 230 m of the channel is lined with concrete; most of the channel is made of earth.

The spans from the starting point to Point No.5+0.0, Points No.7+0.0 to No.46+0.0, and Points No.38+0.0 to No.46+0.0 are planned to be reconstructed using concrete U-shaped flumes (U-300) with a gradient of 1/20. Spans other than the existing concrete ones are to be of earth. For the spans from Points No.1+16.0 to No.2+1.0 and Points No.62+8.0 to No.62+14.0, which are 300 m in length, concrete pipes of 300 mm diameter are planned to be installed in order to cross the road.

c) Diversion and Confluence Facilities

i) Diversion Facilities

There are just 5 diversion facilities made of concrete in the channel. 29 diversion facilities of the total 34 are planned to be reconstructed using concrete.

ii) Confluence Facility

There is a confluence at Point No.26+12.0. As the channel in this span is made of concrete, reconstruction works is not required. However, small incoming stream are to be reconstructed so as to reduce the incoming grit.

d) Protection Facility

The span downstream of Point No.25 runs at the foot of the mountain. Since the mountain has fine soil, there are many points of erosion along the span. To control this erosion, construction of wet masonry wall with a height of 1.0-1.5 m is planned. The total wall length required is 150 m.

10) Sharimochu Channel

a) Intake Facility

The Shariron River, the source of the channel, seeps into the ground near its source during the dry season. In order to utilize the river water effectively, it is planned to construct an intake weir upstream at the seeping point. As a result of field reconnaissance, it was decided to locate the intake point around the elevation of +2,356-+2,357 m. The location meets the above requirements and both banks are suitable for this construction. The weir, with its function of stopping seepage water, will have a deep foundation, 3 m under the ground surface level, at an elevation of +2,354.20 m, taking the present topographical conditions and grit-stones into consideration. Since there are many rolling stones around the intake site, many will be deposited upstream of the new weir. Accordingly, the weir height is to be raised to +2,359.80 m, viz., 2.6 m above the ground surface, which is a height that won't disturb land utilization on either bank. The intake water level is set at +2,359.30 m.

b) Channel

The channel had been reportedly located along the Shariron River's right bank, but due to flooding of the river, benefitting farmlands and channels were washed away. The channel location, therefore, is planned to be moved to the national highway side, on the left bank of the Shariron River, for easy maintenance. Considering the intake water level of +2,359.30 m, the areas which will benefit, and the elevation of the channel, it will have a steep gradient of about 1/12 or have 50-60 drops, causing high construction costs, in the case of an open channel. In addition, its life span would be shortened and water management would also become difficult. Furthermore, the areas which are to benefit from the channel are presently not used due to soil sediments from flooding and since the location of branch channels can not be confirmed. In the future, for the purpose of channel construction, a plan of the branch channels will make possible the removal of sediments. Thus, the channel is planned to include pipelines which are easy to install, in order to meet the work site conditions. The pipeline system will have two tanks (H=2.5 m) at its terminals and four at turning points. These tanks will be connected with polyethylene pipes (Diameter=225 mm). Tanks other than at the starting point are for distribution to branches and for pressure regulation. The standard covering depth of the pipe will be 60 cm.

c) Distribution and Regulation Facilities

i) Distribution Facility

Two valves for distribution will be installed at each of the above-mentioned distribution tanks.

ii) Regulation Facility

For the control of water flow and water level, stop valves will be installed at the inlets/outlets of the main pipeline.

d) Protection Facility

Regulating the structure of the intake facility, although grit coming into the pipeline will be minimal, a screen will be installed at the entrance of the intake to catch tree leaves.

(4) Basic Design Drawings

Basic design drawings are shown in the following pages.

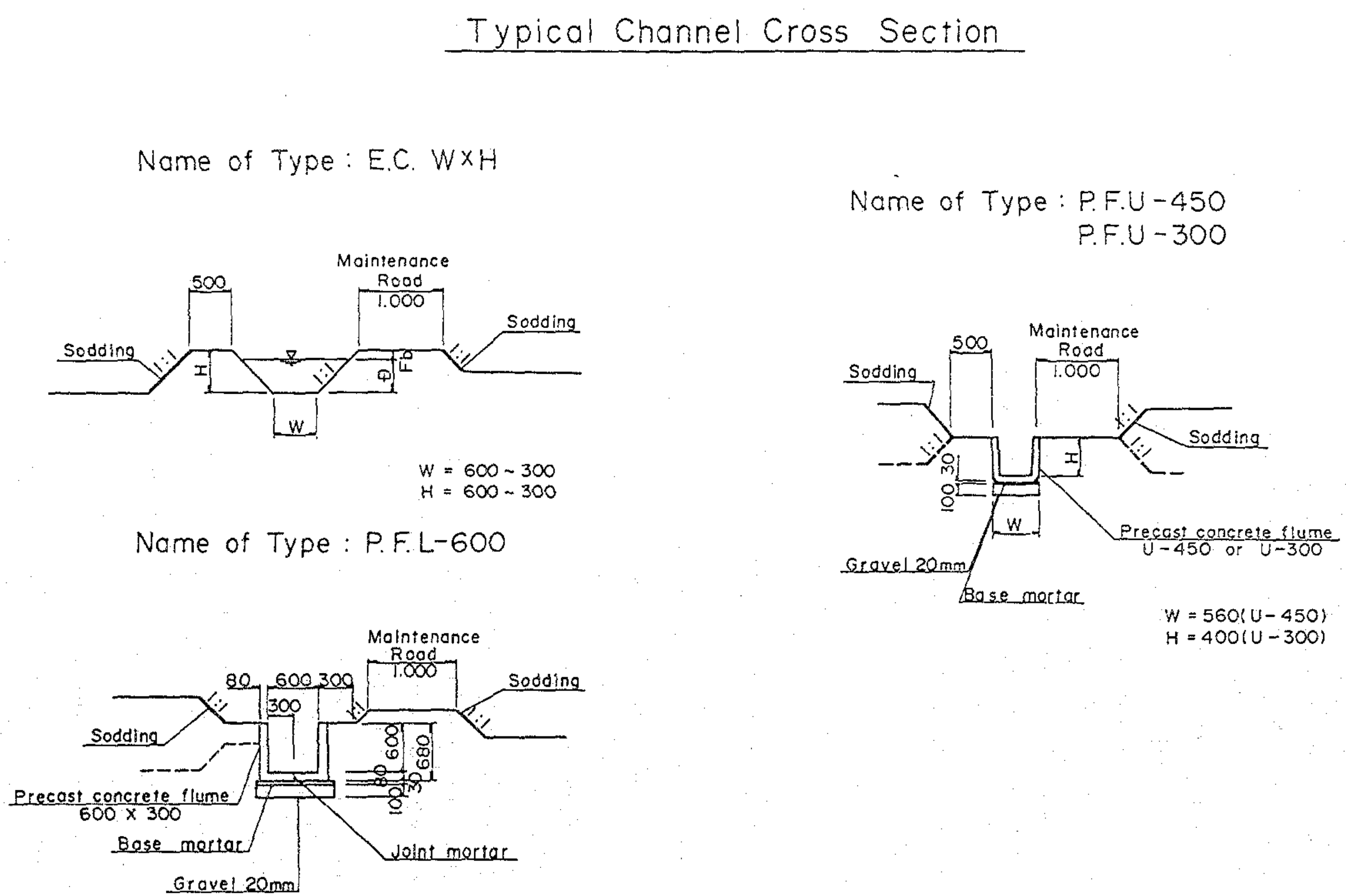
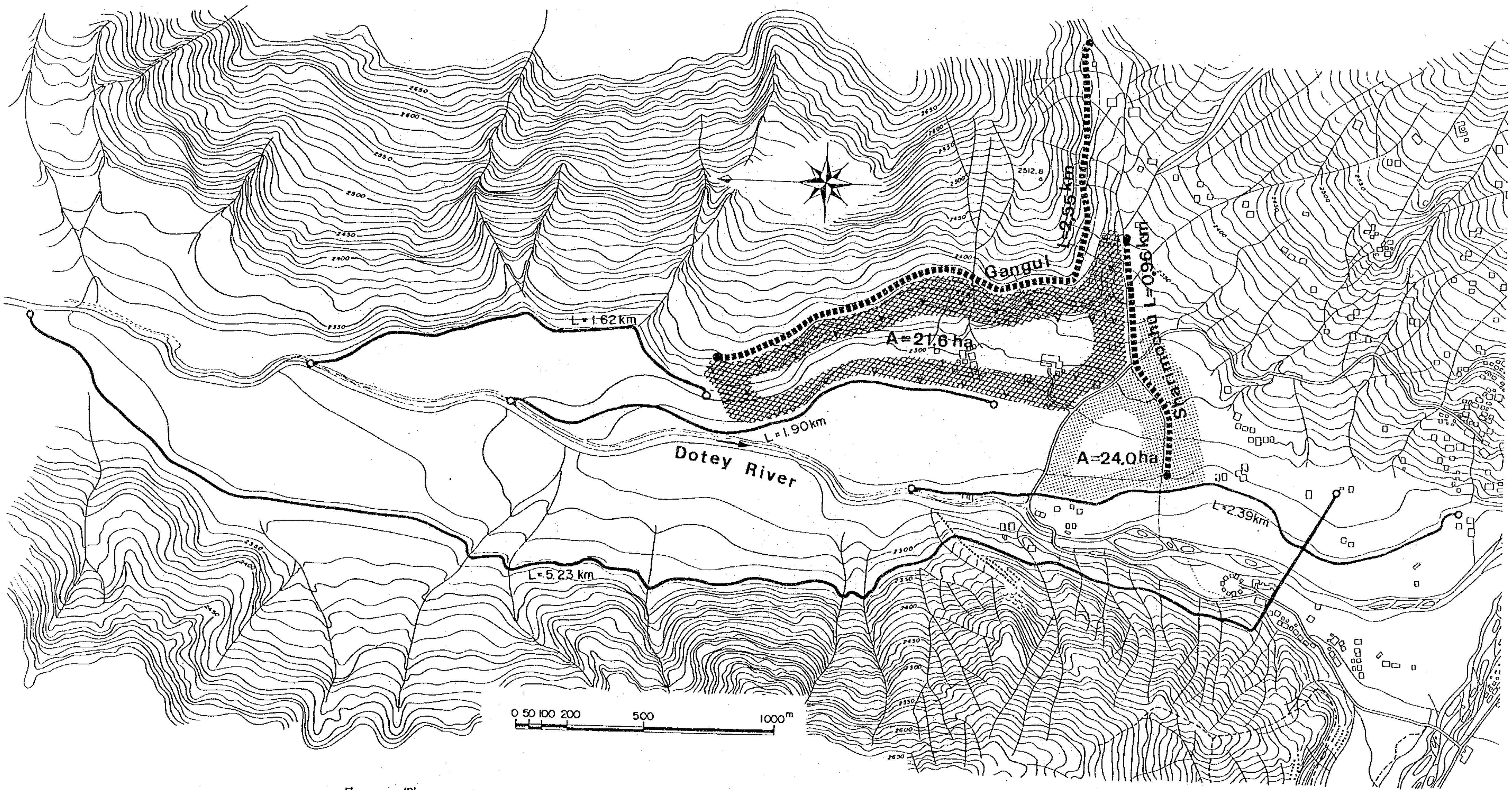


Fig. 5.1 Standard Design of Irrigation Channel



凡　例

○——○ : Stage1.2 （終了）

●▪▪▪▪▪● : Stage2. （今後のステージ）

Fig. 5.2 Irrigation Channel Alignment (1)

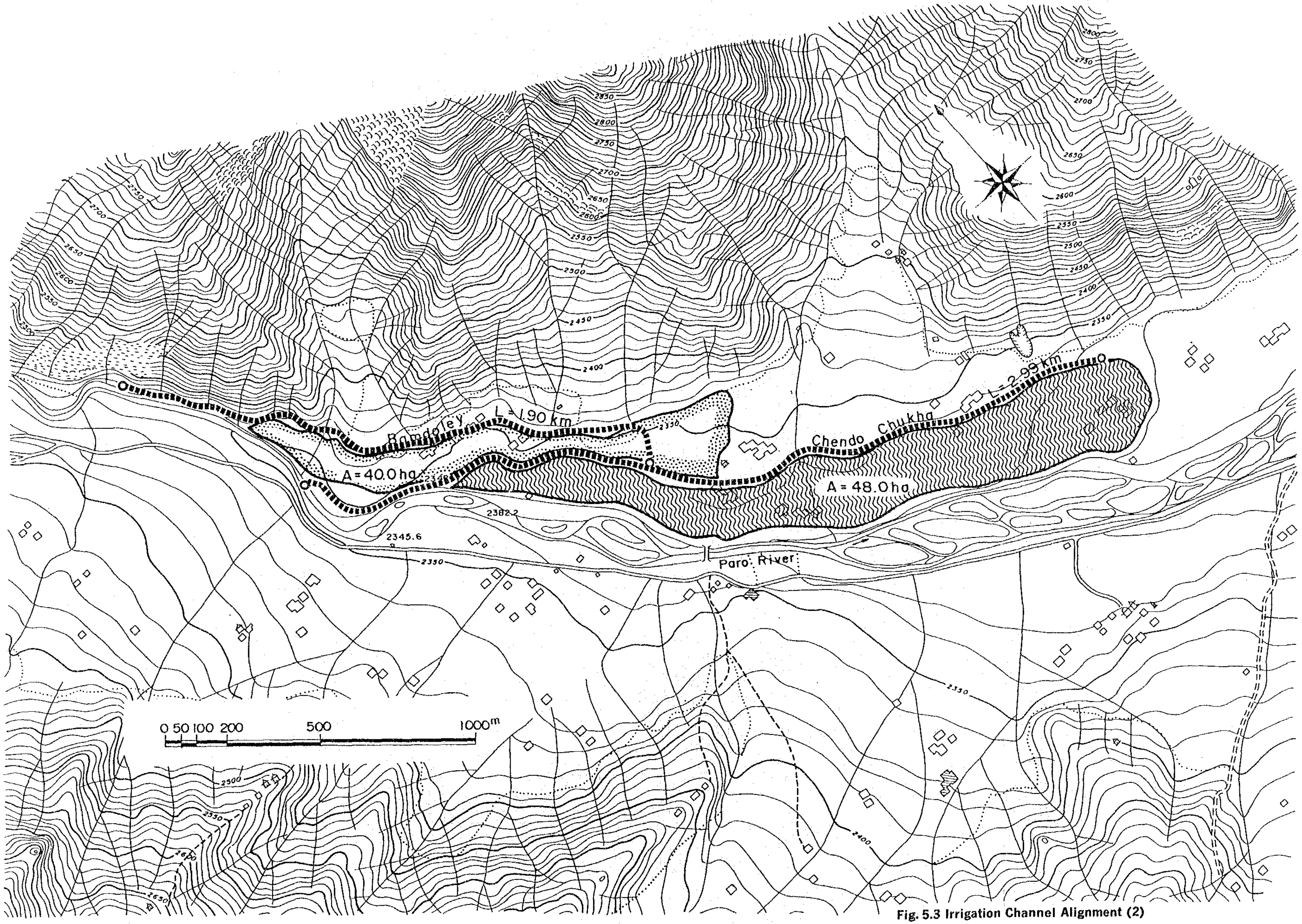


Fig. 5.3 Irrigation Channel Alignment (2)

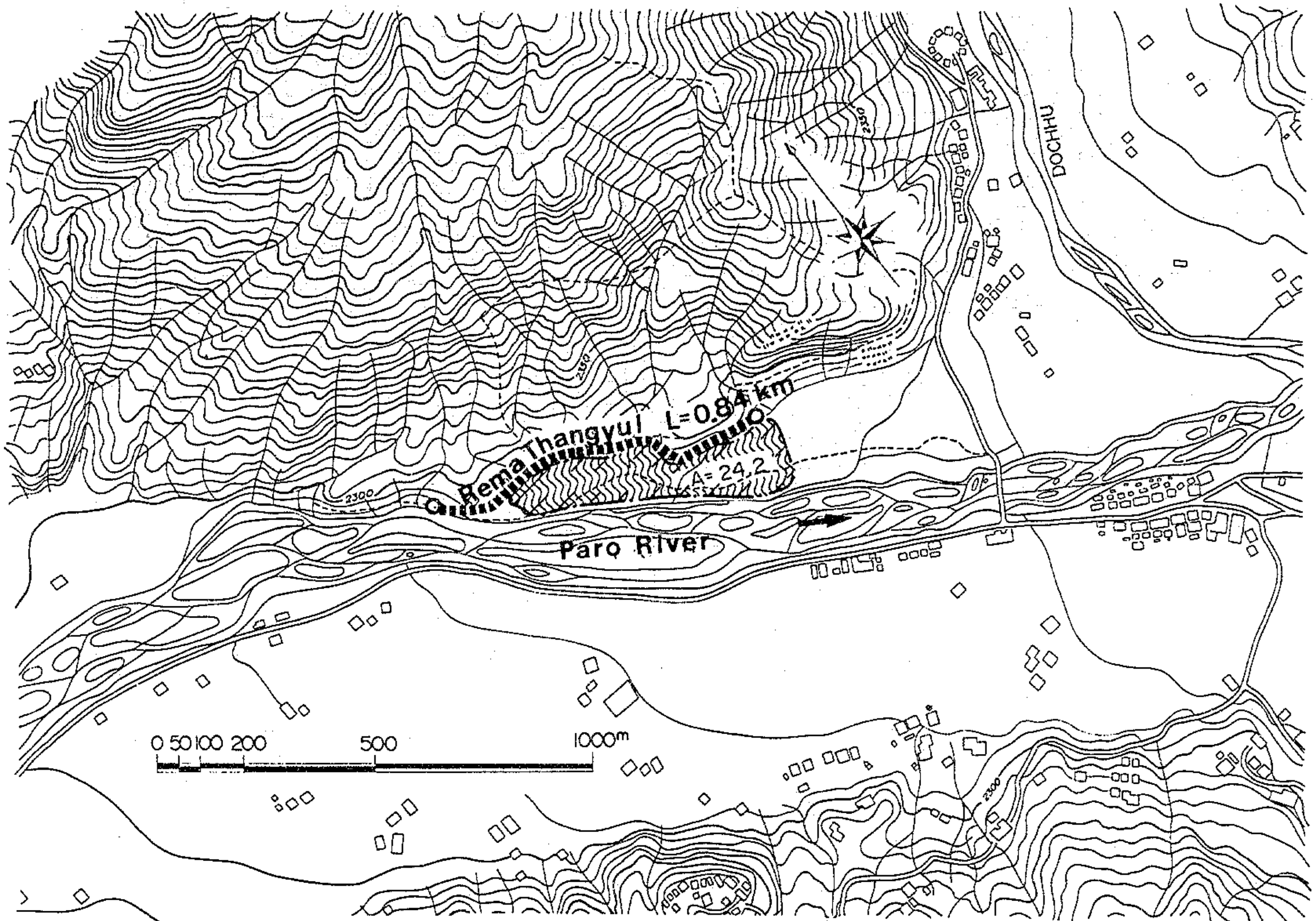


Fig. 5.4 Irrigation Channel Alignment (3)

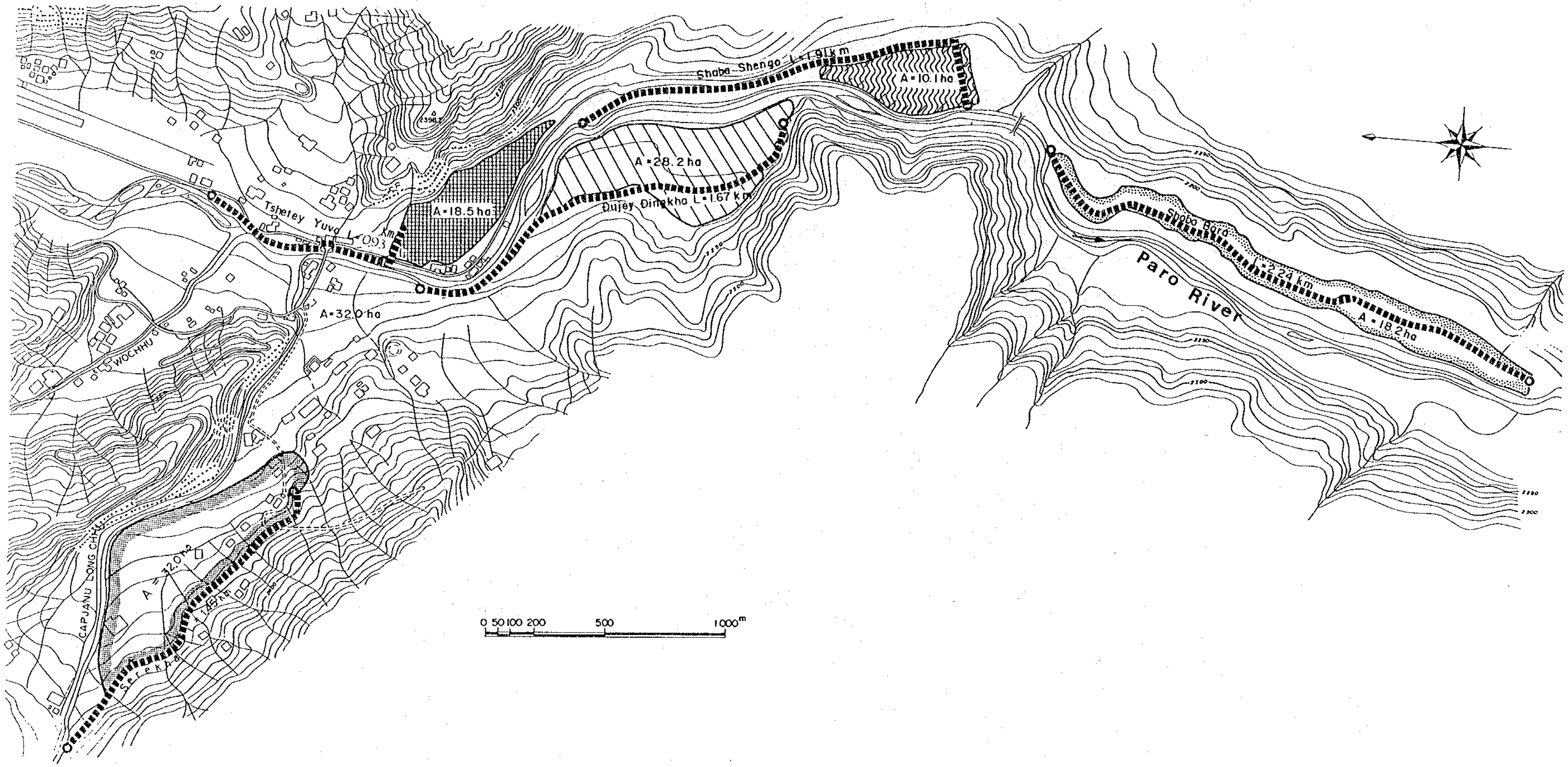


Fig. 5.5 Irrigation Channel Alignment (4)

5.1.2 Farm Roads

(1) Design Policy

The Bamdoley-Jangsa, Nyemizam-Khangkhu and Chorten-Sarpa-Deankha roads are to be designed in combination with river revetment work. The elevations of these three roads are to be calculated in relation to flood water levels.

The Satsam Chorten - Tshongdu road will pass through orchards and paddy fields. The main purpose of the road will be the transportation of the cash crops produced in Gyebjana village. The above two roads must be designed with a balance of soil cutting and banking volume, since there are difficulties in using the forests near the site as a source of materials.

All of the above roads will act as trunk farm roads. Access roads to farmlands and farmhouses are to be constructed by the Government of Bhutan.

(2) Study of Design Conditions

As the existing road network in the project area is inadequate, the proposed farm roads will be planned so that they can be used as general use roads in the future. With this consideration in mind, the designs were proposed as shown below.

Table 5.4 Farm Road Design Conditions

Item	Design Condition
Design speed	30 km/hour
Design load	14 ton
Minimum curve radius	30 m
Minimum curve length	50 m
Maximum longitudinal gradient	8.0 %
Minimum longitudinal curve radius	250 m
Minimum longitudinal curve length	25 m
Maximum steep composite gradient	11.5 %

The installation of transition curves is deemed to be unnecessary, since the speed limits are low and they have not been included in the national highways.

(3) Basic Design

1) Route Alignment and Elevation

Part of the Dotey Farm Road extension, the Bamdoley-Jangsa Road, the Nyemizam-Khangku Road, and the Chorten-Sarpa-Deankha Road act as river banks; therefore, planning shall be done so as not to alter the river sections. Across the river from the Bamdoley-Jangsa Road is the national highway. As shown by the fact that it was damaged by a flood in May 1989 which had a discharge 150 m^3/sec, it would be impossible to protect roads from flooding in the future as they exist, since future flood discharges are estimated at 710 m^3/sec up to the Paro confluence. This estimate is based on the traces of the 1968 flood. Therefore, it is not recommended to merely raise the bank height in the span of the road to be constructed. This span is to have the same elevation as the national highway. In addition, the construction of a comparatively large bank as mentioned above is considered an overinvestment at present, from a flood control economy point of view.

The Nyemizam-Khangku Road is across the river from the Paro Airport; the situation is similar to that for the Bamdoley-Jangsa Road. Accordingly, elevation of the road is planned as above.

As for the Chorten-Sarpa-Deankha Road, flooding will probably not happen, since the opposite side is mountainous. The elevation of the road will be the water height of the 1968 flood, estimated to have a 1,040 m^3/sec flow, plus an allowance.

The Satsam Chorten - Tshongdu Road will run for a long distance, and there is little possibility of the acquisition of soil source areas, because all forests along the road are private. Therefore, there must be a balance between soil cutting and banking volumes and a minor discrepancy between the elevation of road surfaces and farmlands must be tolerated.

The Bondey-Gyebjana Road will require a considerable amount of excavation. Stability of the excavated surface should be ensured.

The Dotey Farm Road extension work is upstream on the left bank of the Dotey River. It should have same elevation as the Dotey Farm Road constructed in Stage 1.2, which enables a flood discharge of 330 m^3/sec plus an allowance.

2) Structure of Roads

a) Width

According to the traffic volume survey in the Phase II Study, the total volume, consisting of passenger cars, buses, trucks, power tillers and tractors, was 223 at Taji (200 m south of the Paro Market) and 274 at Shaba, both on the national highway. Judging from the results of a survey at the Paro Market in the Phase 3 study, the traffic volume at the above two points is thought to have increased to some extent. However, as seen on the Dotey Farm Road constructed in the Stage 1.2, the traffic on gravel-surface farm roads is estimated at less than 100 vehicles a day. Accordingly, the road will be designed to have one lane, 3.0 m in width.

b) Road Shoulders

On both sides of each road, 50 cm wide shoulders will be constructed as protection for major structures, a temporary stopping area for cars, space for pedestrians and livestock, and safety to ease traffic flow.

c) Slopes

The banking material to be taken from borrow areas is mainly reddish brown soil. Excavated soil will be used as banking material, with the exception of soil containing large amounts of organic matter. The height of the banks will be less than 3.0 m, and the gradient of the sides will be 1:1.50. The decision as to where to build the Satsam Chorten - Tshongdu Road and Bondey-Gyebjana Road should be made keeping the excavations to a minimum. The gradient of the excavated slope is to be 1:0.5, a common figure in the project area. The slope of the bank facing the river is to be 1:2.0 in order to protect the bank.

d) Sub-base and Base Course

The base course shall be made of materials that can withstand friction, stirring, and shock, as well as abrasion, smashing and weathering caused by weather and so on. It shall also be composed of materials that will not easily move. The road surface must be easy to maintain and repair. To satisfy the above requirements, crushed stones of a 0-20 mm size will be used. The sub-base and base course are determined according to the roadbed composition. Since the roadbed is made up of reddish brown soil, silty sand, and fine gravel, and tamping is to be done using a 10-ton vibrating roller, the base course will be 15 cm thick. A CBR value of 3 can be expected.

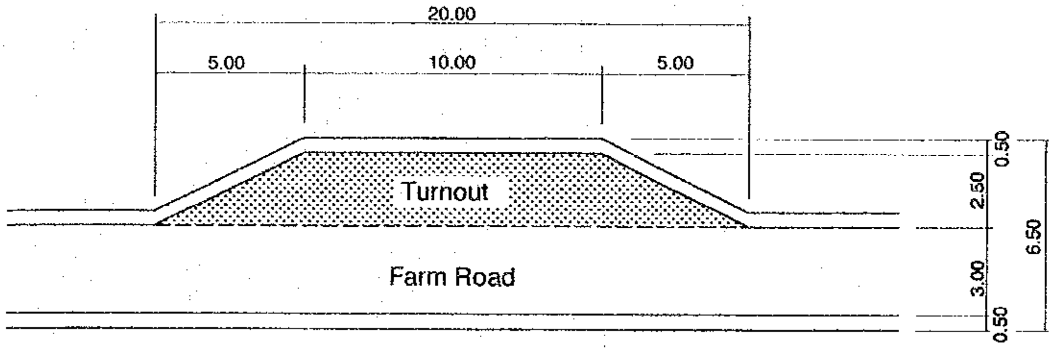
e) Typical Cross Section

A typical cross section drawn up based on the above, is shown in the attached drawing. Gabions will be 40 cm thick and extend 2 m horizontally into the riverbed from the foot of the slope in order to protect it from erosion. Protection sheeting will be installed under the gabions to prevent erosion of the slopes by the river flow. Sodding work will be carried out on the slopes of the inner side of the embankment and the road banking which is separate from the river protection work.

3) Appurtenant Structures

a) Turnouts

Since the road under discussion is a single-lane farm road, turnouts will be provided at maximum intervals of 500 m, so as to ensure smooth passage when there is an oncoming vehicle. The size of the turnouts is shown below.



Turnout

b) Crossing Structures

Small streams, canals, and drainage lines which cross the proposed roads will pass under the road banking through reinforced concrete pipes. In spans where the banking height is low, the vehicular wheel load will act directly on the pipe walls. In such spans, the pipes should be protected with wrapping-concrete.

The pipe diameter is to be determined based on the canal discharge and the farmland area downstream of the crossing point. The reinforced concrete pipes used will be Bhutanese made, with diameters of 225mm, 300mm, 450mm, 600mm, 750mm, 900mm, 1050mm and 1200mm.

Where small streams which have flooded considerably, submersible bridges are to be constructed.

(4) Basic Design Drawings

Basic design drawings for farm roads are shown on the following pages.

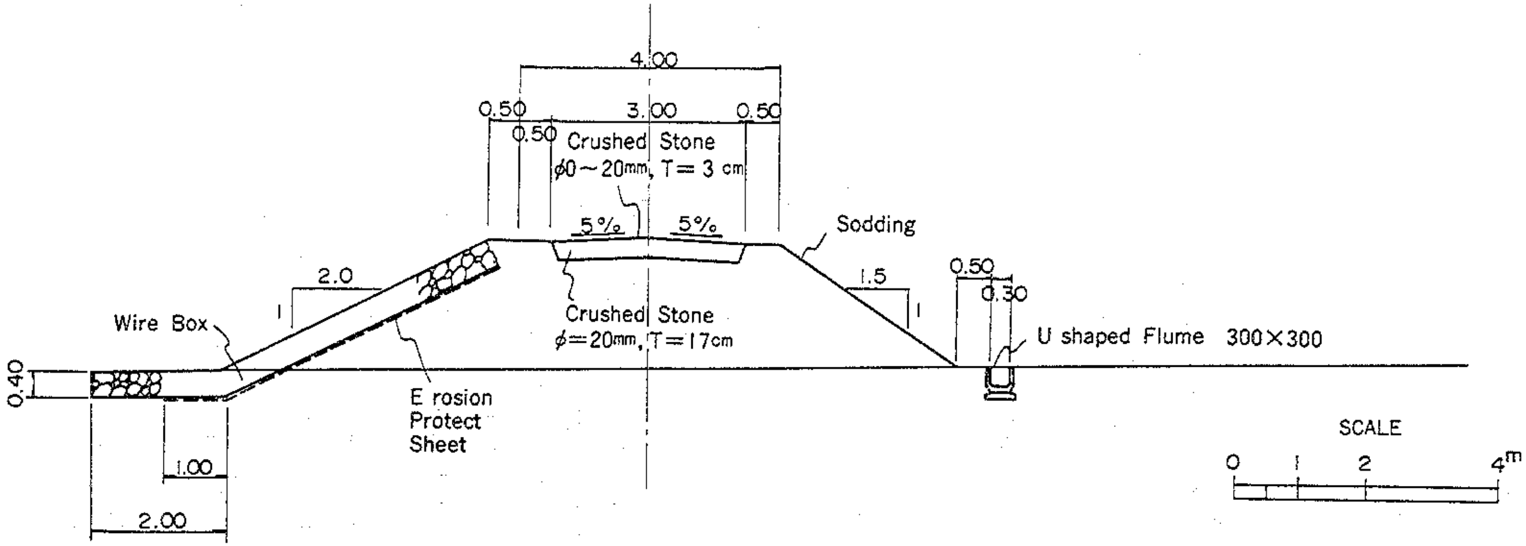


Fig. 5. 6 Farm Road Typical Section

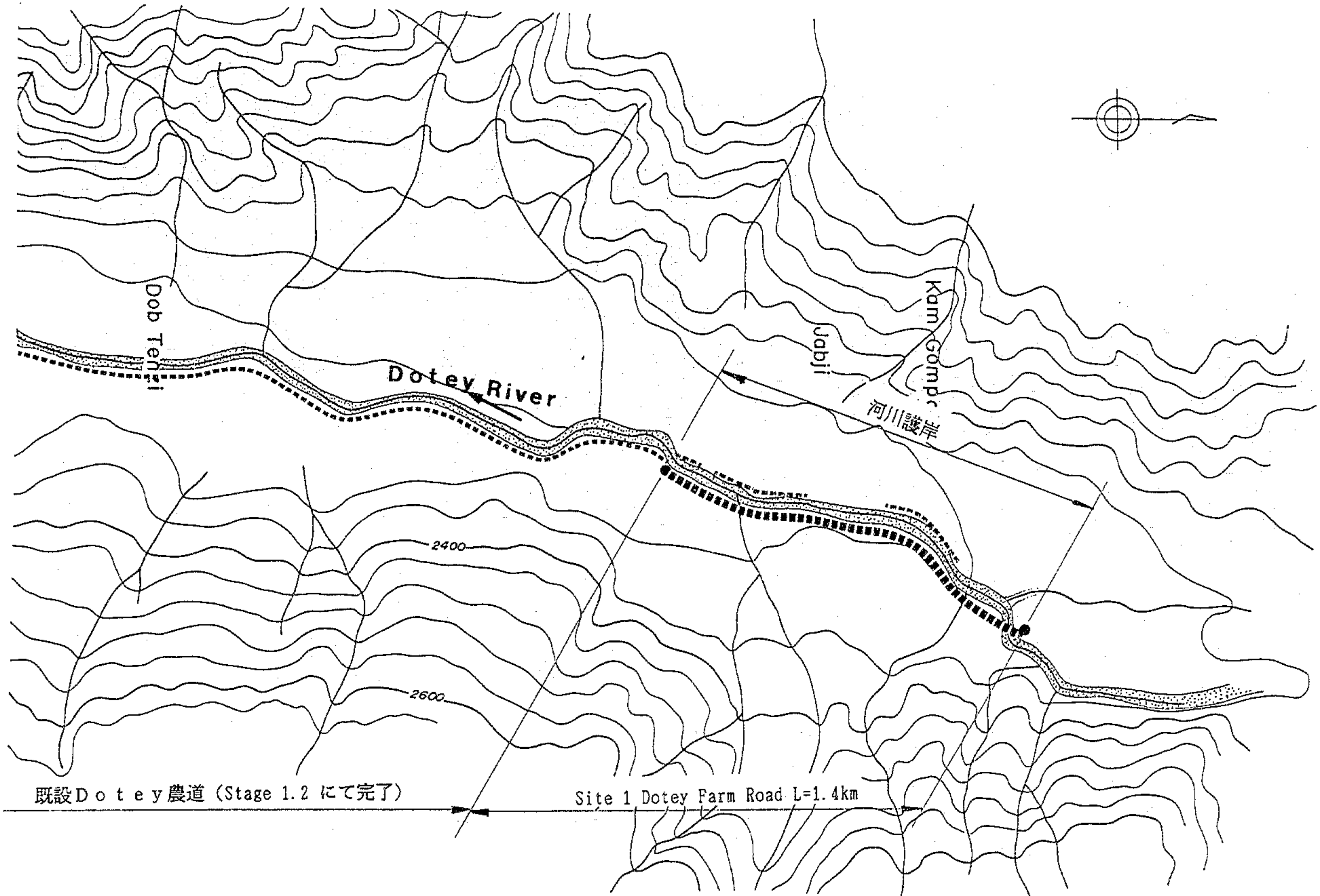


Fig. 5.7 Dotey Farm Road

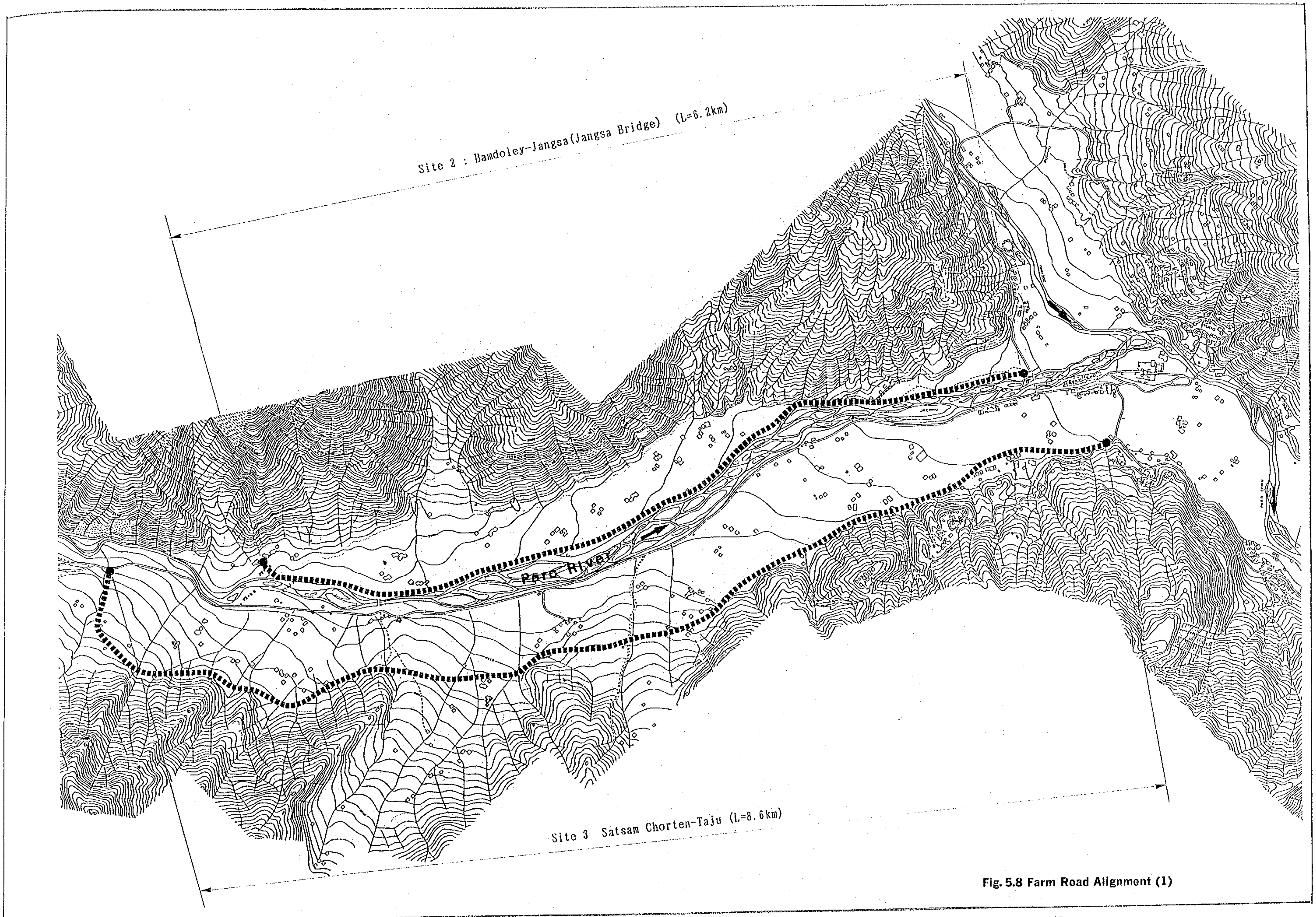


Fig. 5.8 Farm Road Alignment (1)

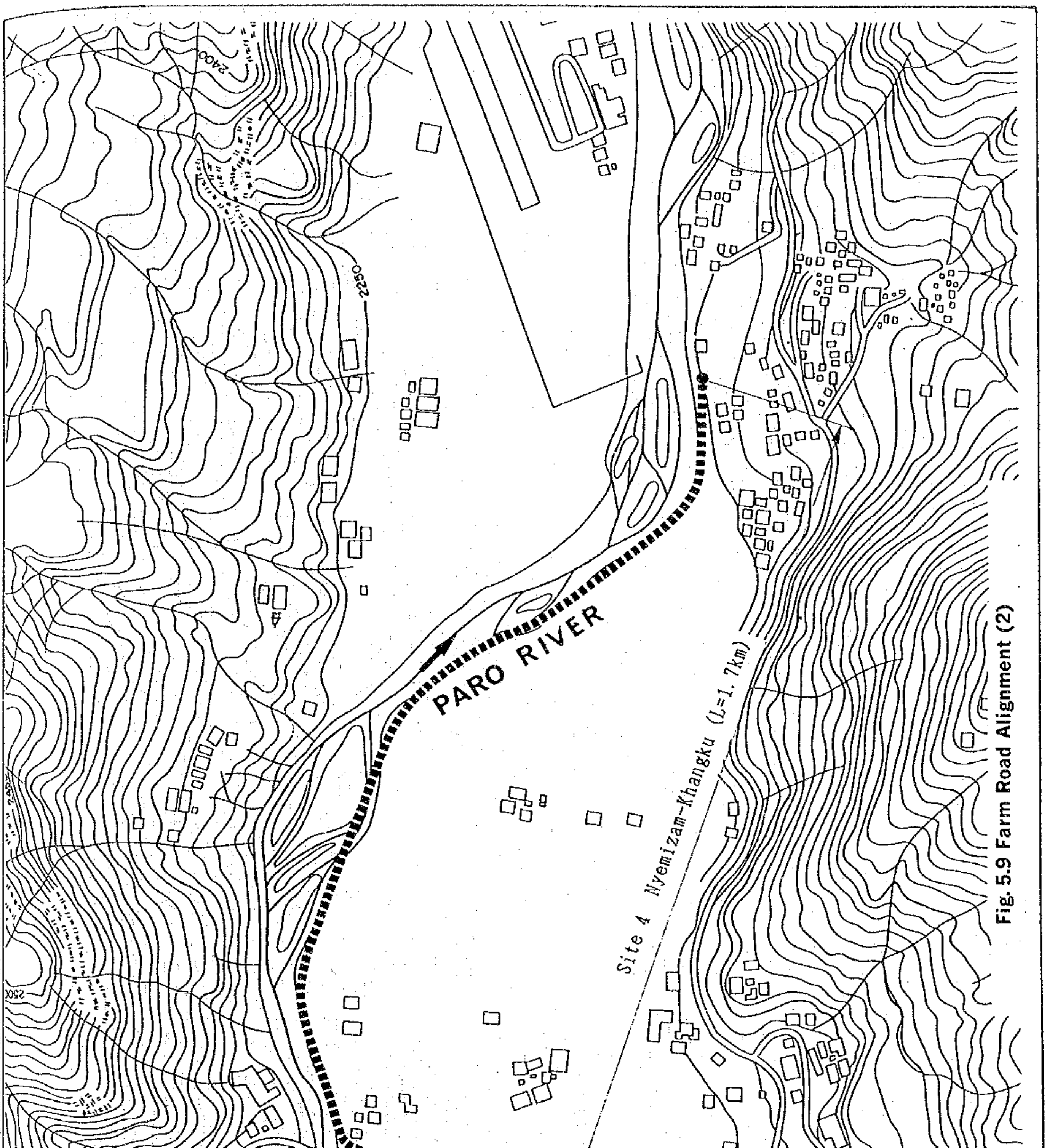


Fig. 5.9 Farm Road Alignment (2)

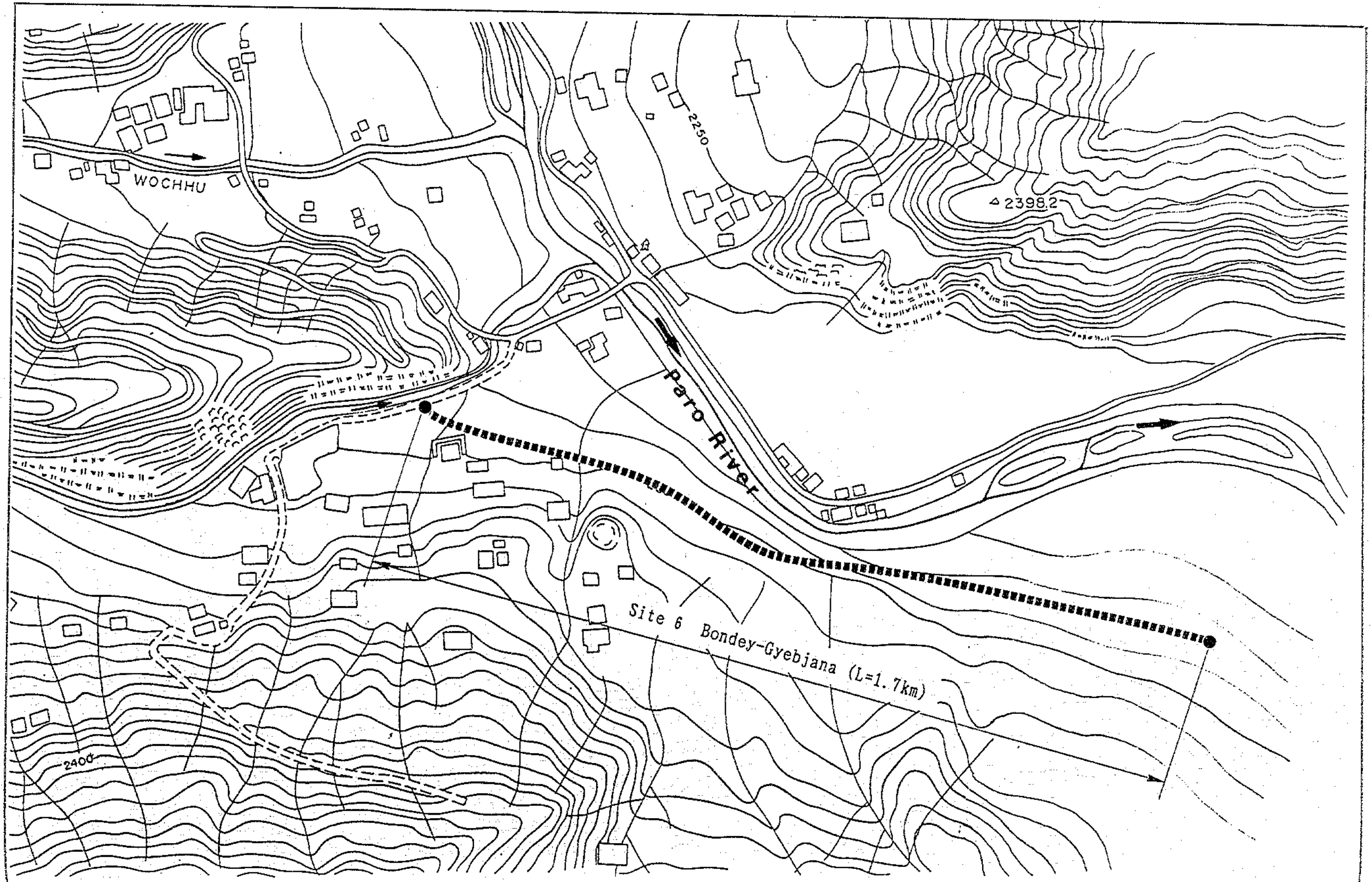


Fig. 5.10 Farm Road Alignment (3)

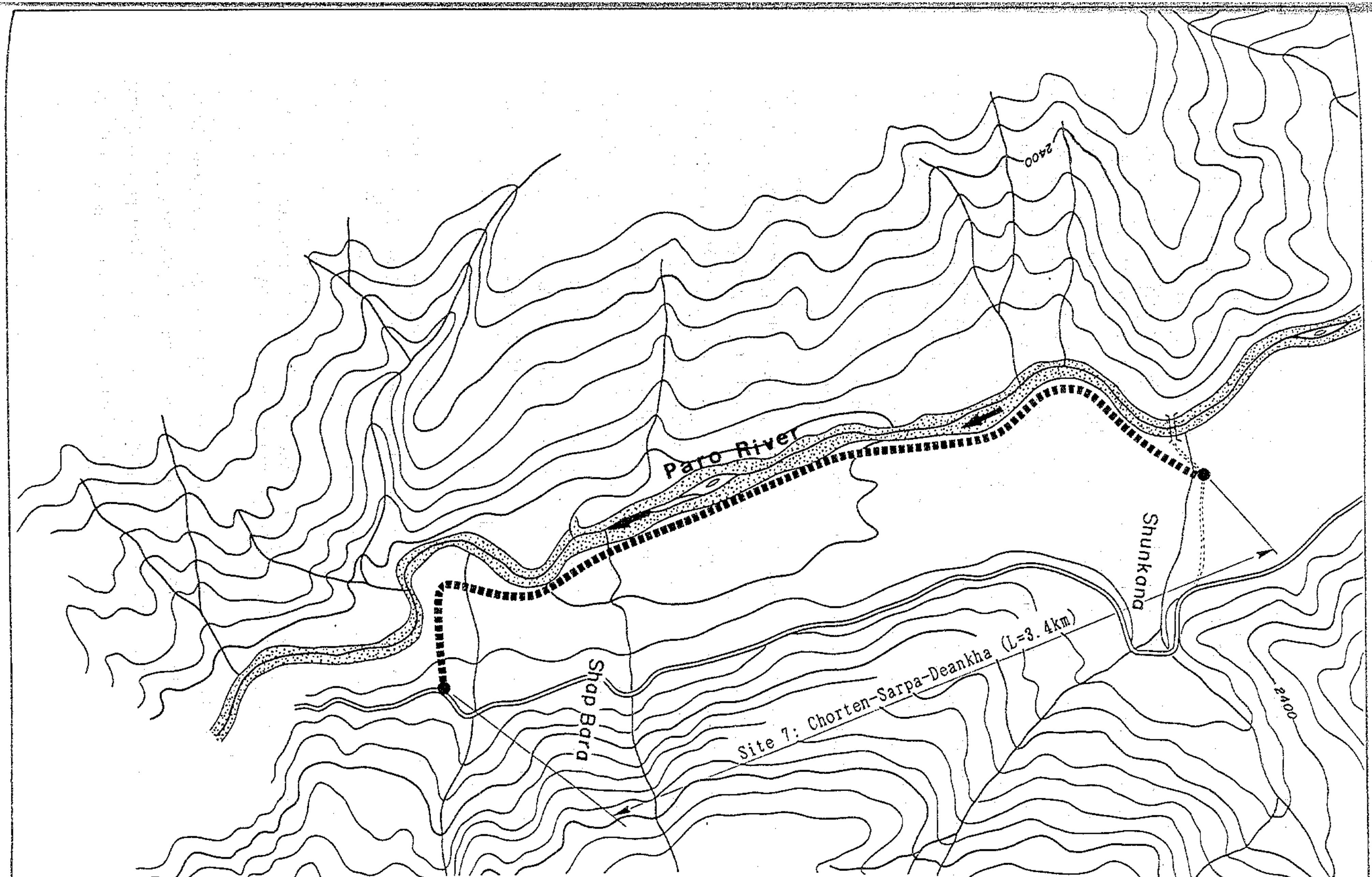


Fig. 5.11 Farm Road Alignment (4)

5.1.3 River Protection Works

(1) Design Policy

As described in the Farm Roads section, the Bamdoley-Jangsa Road, with the national highway opposite it, and the Nyemizam-Khangku Road, with the Paro Airport nearby, will be protected with banking of the same height as that of the opposite bank, so as not to make the opposite side flood. Widening the river is also an alternative to prevent flooding. However, the purpose of the project is to protect farmlands from floods, and change of the river flow should be minimized. The typical structure is to be as given in the preceding Farm Roads section.

(2) Study of Design Conditions

The coefficient of roughness of rivers to be used in calculating flood water levels is 0.05 for the Dotey Farm Road extension, its opposite side, the Chorten-Sarpa-Deankha Road and the Gyebjana Rongchu Road. The elevation of the banks will be the design flood water level. For the Bamdoley-Jangsa Road and Nyemizam-Khangku Road, the bank elevation will be the base line of the river protection, since the flooding is of a smaller scale.

(3) Basic Design

a) Design of Bank Protection

Flood discharge has been estimated based on the traces of the 1968 flood, as given below:

- Dotey River	:	330 m^3/sec
- Paro River, upstream of the confluence	:	710 m^3/sec
- Paro River, downstream of the confluence	:	1,040 m^3/sec

A flood discharge of 151.9 m^3/sec in May 1989 overflowed in the Lango area while a flood of 152.6 m^3/sec in June 1989 did not overflow. This demonstrates that changes in water routes and riverbeds affect flooding to a major extent. It means that the materials that make up the riverbed of the Paro and Dotey Rivers are moving violently even in small to medium-sized floods. The hydraulic condition of the initial movement of riverbed material is defined by non-dimension shearing stress (t*50) given in the following formula (Audrew.E.D. 1984).

$$(t^*50) = DS/(r1/r2 - 1)d50$$

wherein

D	:	Mean water depth
S	:	Gradient of riverbed
r1	:	Density of riverbed material
r2	:	Density of fluid
d50	:	Mean diameter of riverbed-surface material

Movement of riverbed material will occur at the critical value of the above shearing stress, 0.031. The riverbed gradient of the Paro River is 1-2 %. In the case of riverbed cobbles with a mean diameter of 15 cm and more than 1 m of water depth, movement of cobbles is certain to occur. If the water depth exceeds 1.5 m, even cobblestones 30 cm in mean diameter would start to move. In time of flood, the riverbed will easily move, causing the above mentioned damage. Accordingly, in this project, the installation of gabions is proposed as a means of increasing weight. The horizontal part of the gabion work is planned at the foot of the bank in order to prevent slipping. Various materials, such as concrete blocks, chained blocks, cylinder-type gabions, box-type gabions, and concrete work are considered for river protection work. From these, the box-type gabions will be used, since the raw materials for them exist around the site and this kind of work has been done in Bhutan before. The dimensions of the boxes are 0.4 m (h) x 1.2 m (w) x 4.0 m (l) at the maximum.

b) River Course Planning

For the Dotey and Paro Rivers, adjustment of riverbed longitudinal gradient and widening of the river will not be planned, but obstacles to riverflow will be removed. Shrubberies in the river act as natural water-stoppers, but those which grow in the middle of the river make depth vary more than necessary, raise water levels, resulting in floods, and cause bank foundation scouring. Therefore, in the span between Bamdoley and Jangsa, only plants growing within 10 m of the banks on both sides will be left, and others are to be removed. In Gyebjana Rongchu, the river cross-section is narrow at the concrete bridge on the national highway. Nevertheless, rehabilitation of the bridge will not be undertaken in this project since such work has nothing to do with the protection of farmlands from floods and is costly. This river has a steep riverbed gradient of 1/20 on the average and riverbed protection work using gabions will also be done.

(4) Basic Design Drawings

A basic design drawing for the river protection work in Gyebjana Rongchu, which is to be done independently of other work, is shown on the following page. For other river protection work, which is to be combined with the farm road work, refer to the basic drawings for farm roads.

5.1.4 Work Quantities

Work quantities, which were estimated based on the basic design drawings, are given in Table 5.6 for irrigation facilities and Table 5.7 for farm roads and river protection work.

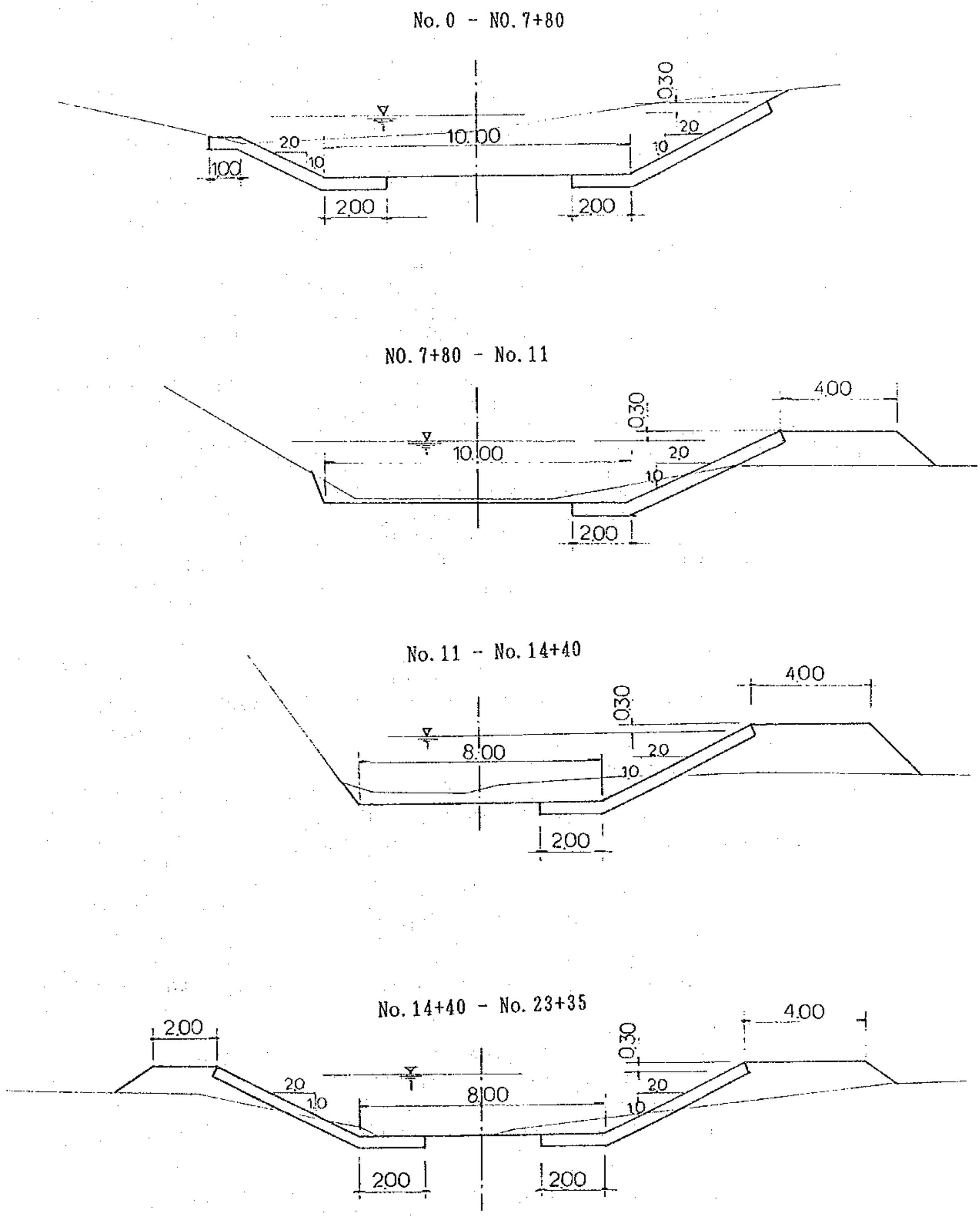


Fig. 5.12 Typical Cross Section — Gyebjana Rongchu River

Table 5.6 Work Quantities (1)
(10 Irrigation Facilities)

Intake Weir		
- Concrete	:	2,280 m^3
- Timber	:	7,020 m^3
- Gabions	:	2,980 m^3
Channel		
- L-shaped concrete flume (L-600x300)	:	2,130 m
- U-shaped concrete flume (U-300)	:	120 m
- U-shaped concrete flume (U-450)	:	690 m
- Masonry	:	830 m
- Earth channel	:	3,780 m
- Polyethylene pipe	:	960 m
Diversion work	:	179 sites
Inlet work	:	5 "
Energy dissipater		
Drop work	:	6 "
Grit chamber	:	6 "
Sediment work	:	7 "
Intake work	:	1 "
Crossing work	:	3 "
Approach channel	:	2 "
Bank protection	:	250 m

Table 5.7 Work Quantities (2)
(Farm Roads and River Protection : 7 sites)

Roads construction		
- Excavation	:	14,750 m^3
- Banking (original soil)	:	46,820 m^3
- Banking (transport)	:	147,150 m^3
- Subbase	:	14,270 m3
- Slope cutting	:	15,940 m^3
- Slope banking	:	69,040 m^3
- Sodding	:	65,850 m^2
- U-shaped concrete flume (U-300)	:	31,850 m
River protection work		
- Gabions	:	109,100 m^3
- Construction sheet	:	79,560 m^2
- Slope work	:	65,030 m^3
- Riverbed excavation	:	48,600 m^3
Submersible bridge		
- Concrete	:	350 m^3

5.2 Jangsa Bridge

5.2.1 Design Policy

Regarding the reconstruction of the Jangsa Bridge, the basic policy is as follows.

1) The size of the bridge is to be, in principle, that of the existing bridge. However, the future traffic system and use of construction equipment in the project will both be considered.
2) The existing bridge is insufficient both in its impediment to riverflow and in its vertical clearance between the high water level and the bridge slab. These problems will be rectified.
3) For the selection of the type of bridge, its construction in the rainy season will be considered as well as the official implementation period of the grant aid project.
4) As the bridge site is adjacent to the Paro Market, consideration should also be given to pedestrians.
5) As the maintenance costs will be borne by the Government of Bhutan, the bridge should be the type which has low maintenance costs.
6) In order to increase the riverflow capacity, bridge piers will not be constructed in the center of the river. Protection work for the riverbed and river banks will be done.
7) The height of the superstructure should be so designed as to not make the access roads steep.

5.2.2 Study of Design Conditions

(1) Design Standards

a) Road Construction Manual (RCM)
(by the Public Works Department: PWD)
b) Standard Specifications and Code of Practice for Road Bridges(SSCP)
(by the Indian Roads Congress, India: IRC)
c) Standards of Road Bridges
(by the Japan Road Association)

(2) Design Loads

The following loads will be used in the design.

a) Live Load

The design live load will be from the Standards of Road Association, 20 tons of vehicle load (T-load and L-load) plus sidewalk live load.

i) Design of Slabs

- Carriageway:

T-20 load will be used. T-load shall be placed on the part where the maximum stress would occur.

Table 5.8 T-Load

- Design load	: T-20
- Total load	: W=20 ton
- Front wheel load	: 0.1W = 2 ton
- Rear wheel load	: 0.4W = 8 ton
- Width of front wheel	: b1 = 12.5 cm
- Width of rear wheel	: b2 = 50 cm
- Grounding length of wheel	: a = 20 cm

- Sidewalk:

A sidewalk load of 500 kg/m^2 (uniform load) will be used.

ii) Main Girder Design

L-load consisting of one-linear load and uniform load will be considered on the carriageway of one span of the bridge. The L-load is to be put on the design point or the design member so as to act most disadvantageously. In the area of the carriageway which is 5.5 m wide, the linear load (P) and the uniform load (p) will be considered.

2) Load Impact Factor

The load impact factor is based on the Standards of Road Bridges, and the following formula will be applied.

Load impact factor : $i = 20/(50+L)$

3) Dead Load

Dead loads consisting of bridge weight, handrails, attached water supply pipeline, lighting equipment, etc., will be calculated using the following unit weights.

Table 5.9 Unit Weight of Materials

(Unit : kg/m^3)

Material	Unit Weight
Steel, cast steel, forge steel	: 7,850
Cast iron	: 7,250
Aluminum	: 2,800
Reinforced concrete	: 2,500
Prestressed concrete	: 2,500
Plain concrete	: 2,350
Cement mortar	: 2,150
Asphalt for pavement	: 2,300
Concrete for pavement	: 2,350
Wood	: 800

4) Seismic Load

In accordance with RCM, the seismic factor of K=0.14 will be applied to the above dead loads.

5) Others

Other loads such as earth pressure, water pressure, buoyancy, shrinkage of concrete, and creeping stress will be considered. Further, wind load, temperature variation, ground settling, loads during construction, movement of support points, collision loads, and braking loads will be considered, when necessary.

(3) Design Strength

The design strength of each member is as follows:

a) Concrete

Concluding from the experience had in Stage 1.2, the concrete made from Bhutanese cement was not sufficiently strong for bridge construction work which requires a concrete strength of more than 210 kg/cm^2. In the current study, the basic design study Phase III, 2 kinds of Bhutanese made cement and 3 kinds of Indian made cement were handcarried to Japan for testing purposes. The tests consisted of a physical test and a chemical test. The Indian cement was tested for chemicals only. The test results are given in the Appendix 12. Mortar made of ordinary Bhutanese cement gave a compressive strength of less than 210 kg/cm^2. Generally Bhutanese cement is used for small structures; and for large structures, high-quality cement is used. High quality cement is not produced ordinarily and a sample was not obtained. From the results of the ordinary cement tests and quality certificates for both ordinary cement and high-quality cement showing compressive strength, the design compressive strength has been determined to be 210 kg/cm^2, provided that Bhutanese-made high-quality cement be used.

b) Steel Material

Steel for the superstructure is planned to be procured in Japan. The strength of this steel is to conform with JIS. Steel bars made in India are planned to be obtained in Bhutan. Their strength is almost the same as that of Japanese deformed steel bars (SD30).

5.2.3 Basic Design

(1) Location and Layout Plan

The existing bridge shall not be demolished until the new bridge is constructed. Accordingly, the location of the new bridge should be either upstream or downstream of the existing bridge. A major factor in the selection of the bridge location is that of access roads. An alternative to a downstream location is a site between the existing bridge and the Paro Market, located about 100 m from the existing bridge. If the new bridge were to be located about 15 m downstream from the existing bridge, there is a police station building under construction on the right bank which would be in the way. Moreover, on the left bank, it would be necessary to construct an access road which would gradually curve to the existing access road and require a great deal of farmland acquisition. A location further downstream would make access from the left bank more difficult.

On the other hand, the existence of private houses is a complication of the upstream location alternative. There are 2 private houses on the right bank in the area around 25 m upstream to 50 m upstream from the existing bridge. There is 1 house on the left bank 100 m upstream. The Government of Bhutan will move the houses, if necessary. However, this would like to be avoided, if possible. Accordingly, on the upstream side, a point either 15 m or 70 m from the existing bridge would be the new bridge construction site. In the latter case, a lot of farmland would be required for access roads and the topographical situation is not favorable. If the point 15 m upstream were chosen, construction of a retaining wall would be necessary in order to avoid moving the houses. It was decided, however, that construction of a wall is not a large constraint, either technically or financially. Further, this plan would allow the access road on the left bank to be straight. Therefore, the point 15 m upstream is the best for the new bridge construction site.

The existing bridge is somewhat obliquely placed. It is recommended to build river structures at a right angle to the riverflow for stable riverflow and for security of the structures. With this in mind, the centerline of the new bridge was determined to be on the line which connects a point 15 m upstream from the existing bridge on the right bank with a point 23 m upstream on the left bank.

(2) Dimension Determination

1) Width

As the purpose of the new bridge is basically to replace the existing bridge, logically, the new bridge would have a one-lane width, the same as the existing one. The results of the traffic volume survey show that the present traffic volume is that of a one lane road. In the Seventh Plan, construction of new roads and extension of existing roads are not proposed, just repair work on existing roads and realignment work. It is not anticipated that the traffic volume would increase markedly in the short term due to the consolidation of socio-capital infrastructure. However, judging from the GDP growth rate, the number of vehicles has been forecasted to increase in proportion to the economic growth, and traffic volume would therefore increase.

In order to determine an appropriate bridge width, the widths of other bridges on national highways and district roads and the widths of their access roads were surveyed. The results are in the following Tables.

Table 5.10 Bridge Width

Bridge	Road	Width of Carriageway	Width of Sidewalk	Location
- Tshuzong Bridge	National Highway No.1	7.5 m		Boundary of Paro and Thimphu
- New Bondey Bridge	National Highway No.1	7.5 m		Near Paro Airport
- Jangsa Bridge (Existing)	District Road	3.7 m	0.75 m x both sides	Near Paro Market
- Shari Bridge	District Road	3.7 m		Between Paro Market and Dzong

Table 5.11 Road Width

Location Surveyed	Width of Road
Access road to Jangsa Bridge, left bank side	5.0 - 5.5 m
" " , right bank	5.0 - 10.0 m
National Highway No.1, Paro Market	8.0 m
" " , south of Paro Market	4.0 m
" " , north of Paro Market	4.0 m

Looking at the information from the two tables together, the Jangsa Bridge is to be compatible with the access road on the right bank side to the Jangsa Bridge. Thus, the width of the new bridge will be 5.5 m, which is comparatively wide for one-lane roads and will allow two-way traffic.

2) Length of Bridge

A river improvement plan for the Paro River has not been established. For the purpose of determining the new bridge length, a topographical survey of the riverbed around the existing bridge was carried out. As a result, it was found that the river around the bridge was wider than upstream or downstream, and a bridge length of 100 m, approximately the length of the existing bridge, would be sufficient.

3) Vertical Clearance and Design High Water Level

The design high water level and the vertical clearance between the high water level and the girder were studied to determine the elevation of the girder.

i) Design High Water Level

Generally, the design high water level should be based on the flood water level and the bank design elevation should be designated by the river improvement plan. However, such a plan for the Paro River has not been established. The riverflow capacity at the existing bridge is estimated to be smaller than a possible flood discharge. It is considered uneconomical to do river control work based on a large flood which might occur once every 50-100 years. Therefore, the design high water level for the new bridge is to be based upon the size of floods which are likely occur within 30 years.

From a survey taken at the site, it was found that the largest flood in the last 35 years happened in the year 1968. Taking a decrease in flood occurrence due to the construction of small-scaled banks after that into consideration, the 1968 flood is considered to be at least a "30 year probable flood". The maximum water level in the 1968 flood was 0.5 m lower (+2,268.55 m) than the girder of the existing Jangsa Bridge. From the hydraulic calculation, the flood discharge is estimated at 710 m^3/sec, which is to be the design discharge. (For details, refer to Appendix 11.)

ii) Vertical Clearance

The vertical clearance is in conformity with the Standard Specifications and Code of Practice for Road Bridges by the Indian Roads Congress (SSCP) which is used for design standards of the roads and bridges in Bhutan. The standards set the criteria shown below: 1.20 m clearance for a design flood discharge of 710 m^3/sec.

Table 5.12 Vertical Clearance
(by SSCP)

Design Discharge (m^3/sec)	Vertical Clearance
Less than 0.3	: 0.15 m
0.3 - 3.0	: 0.45 m
3.0 - 30.0	: 0.60 m
30.0 -300.0	: 0.90 m
More than 300	: 1.20 m

iii) Elevation of Girder Bottom

The elevation of the girder bottom is designed at +2,269.75 m, which is equivalent to the design high water level (+2,268.55 m) plus the vertical clearance (1.20 m), and 0.7 m higher than that of the existing bridge.

4) Depth of Foundation

Scouring depth is thought to be fairly deep, because the riverbed longitudinal gradient is steep, as much as 1/75 - 1/100, and the river-bed frequently moves. For the purpose of scouring prevention, riverbed protection work should be performed sufficiently. The depth of the bridge pier foundations should be more than 2.0 m, from the upper surface of the foundations to the lowest riverbed point.

5) Riverbed Protection

In order to stabilize the riverbed and protect the pier foundations, riverbed protection work is proposed. The work is large in scale, and the use of precast concrete blocks is difficult, taking into consideration the limited construction period. Hence, the work is planned to be carried out using gabions. In general, the weight of one gabion is determined considering the riverbed materials, water depth, flow velocity, etc.; the criteria in Table 5.13 are also applied.

Table 5.13 Weight of Riverbed Protection Work

(Design high water level gradient) x (Design water depth)	Weight of riverbed protection work per piece
Less than 1.0 x 10(**-2) m	About 1.0 ton
(1.0 - 2.0) x 10(**-2) m	About 2.0 ton
(2.0 - 3.5) x 10(**-2) m	About 2.0 - 3.0 ton
More than 3.5 x 10(**-2) m	More than 3.0 ton

In the case of a design water depth of 2.55 m and a design high water level gradient of 1/100, the weight of the gabion required will be 2.5 ton. Supposing that the size of the gabion is 1.5 m x 1.5 m, the necessary thickness of the gabion would be about 1.5 m. Such a big gabion would be difficult to make. In conclusion, the riverbed protection work will be gabions with thicknesses of 50 cm put across the whole riverbed 20 m upstream and downstream from the foundation, making a total length 48.3 m. At both ends upstream and downstream, barrier work is to be constructed so that the gabions will not move.

(3) Selection of Bridge Type

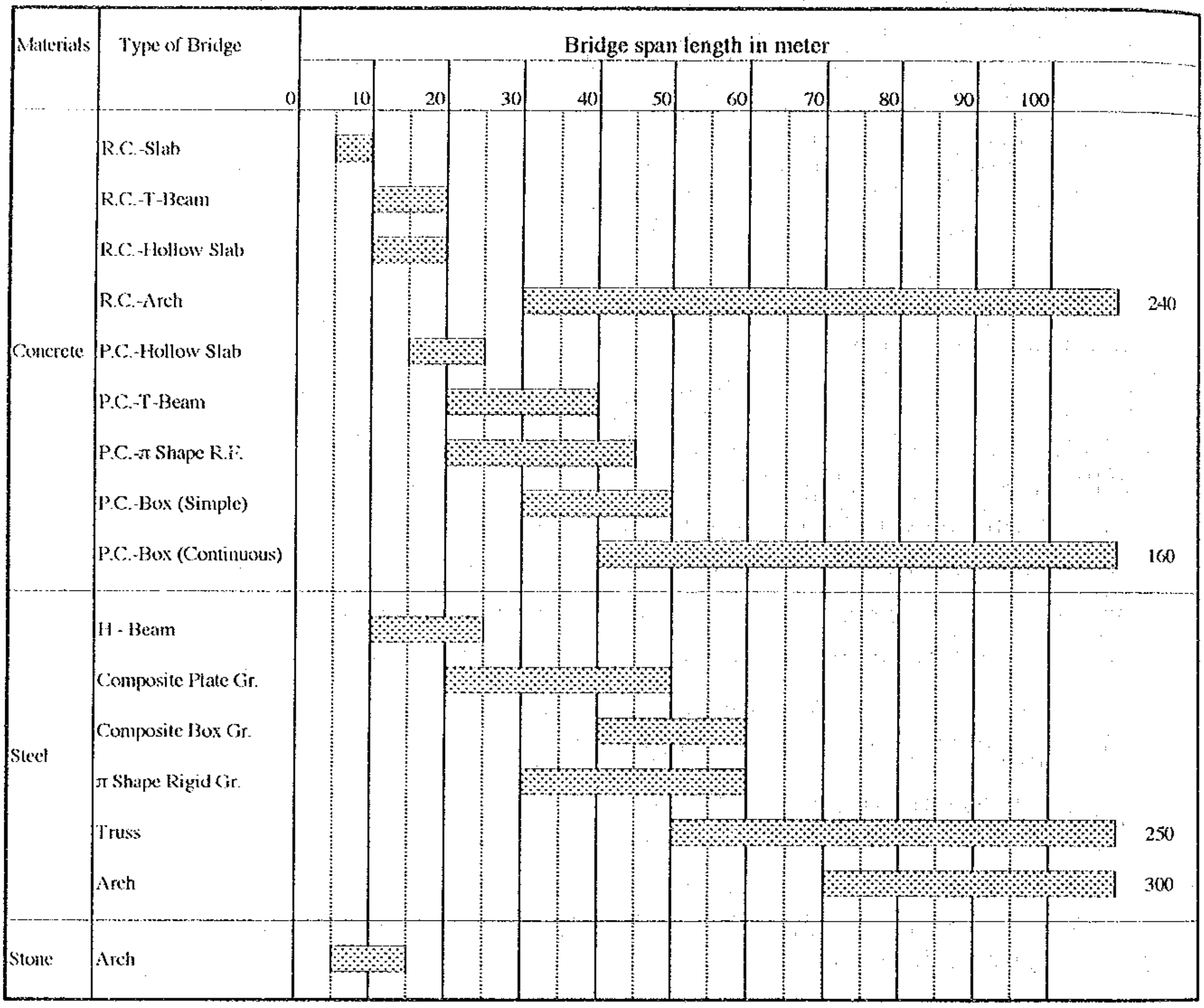
1) Possible Bridge Types

In general, the bridge types which are plausible for a bridge of this scale are as follows.

a) Reinforced concrete bridge	:	Slab, T-beam, hollow slab, arch
b) Prestressed concrete bridge	:	Hollow slab, T-beam, pai-beam, box-beam
c) Steel bridge	:	H-beam, plate girder, box girder,pai-girder, truss, arch
d) Masonry bridge	:	Arch

Considering construction costs and construction time, reasonable span lengths are as given in Table 5.14.

Table 5.14 Type of Bridge and Span Length



A prestressed concrete bridge usually has an economic advantage in bridges of this scale; yet requires work facilities, a long construction time, and designated concrete strength (300-400 kg/cm^2). At present, production of high strength concrete is difficult due to material constraints. Steel girders are to be imported, but this construction method requires a construction time which is shorter than that of concrete bridges, and the work is comparatively possible during the wet season.

From the above factors, either a T-beam reinforced concrete or an H-shaped steel girder type bridge is conceivable. A comparative study is as below.

2) Comparative Study of Bridge Types

As the span lengths increase, the number of piers decreases, thus making construction time shorter and impediment (Total width of piers / Riverflow width) to riverflow smaller. On the other hand, long spans require a larger beam girder height, which increase the access road's gradient, resulting in an elevation of the road surface of the national highway and the necessity for additional improvement work on the national highway. Considering the above, 4 alternative combinations of span length and bridge type are studied below. (See drawings in the Appendix 7.)

Table 5.15 Bridge Construction Alternatives

Alternative	Type of Bridge	Height of Beam	Span Arrangement
Type-A	7 spans, T-beam reinforced concrete	1.365 m	14.3 m x 7 spans
Type-B	7 spans, H-shaped steel girder	1.12 m	14.3 m x 7 "
Type-C	5 spans, H-shaped steel girder	1.23 m	20.0 m x 5 "
Type-D	4 spans, I-shaped steel girder	1.32 m	25.0 m x 4 "

Table 5.16 Comparison of Alternatives

Alternative	Type-A	Type-B	Type-C	Type-D
Impediment to riverflow	6 %	6 %	4.8 %	4.2 %
Workability	Bad	Good	Good	Good
Construction time	18 months	15 months	14 months	13 months
Maintenance	Fair	Fair	Good	Good
Rate of construction cost	1.00	1.04	1.00	1.10
Highway elevation necessity	1.00 m	0.85 m	1.00 m	1.10 m

The existing bridge has 15 piers. The rate of impediment to riverflow is 13 %. A change to about 5 % is to improve the flow capacity in time of flood, resulting in a stabilization of the riverbed and flood protection. In a comparison between Type-C and Type-D, the construction cost of Type-C is cheaper, because the elevation of the national highway in Type-C is smaller and the road distance to be elevated is shorter. Type-C has 4 piers and none of them is located at the center of river-flow, an advantage from a riverbed scouring point of view.

Therefore, the Type-C alternative is recommended to be built in this project.

(4) Basic Design

1) Superstructure

a) Steel Girder Type

A required condition for the beams of the new Jangsa Bridge is to have a minimal beam height, since the beams will be connected to the access road and the required vertical clearance from the high water level to the beam is 1.20 m (the existing bridge : 0.5 m). In order to satisfy this requirement, an H-shaped steel girder will be employed for the following reasons.

- Compared to the built-up steel girder which is manufactured initially from steel plate, the H-shaped steel girder is cheaper because it is manufactured using a roll method and the manufacturing process is relatively simple.
- Compared to the built-up steel girder, the H-shaped girder has a 50 % shorter height; it has an advantage in terms of maintaining the vertical clearance.

- Economical lengths of the H-shaped steel girder range from 10 m to 25 m; this matches the span of 20 m proposed.
- Antiweather type H-shaped steel girders which are maintenance-free are available.

b) Steel

In a comparison between ordinary steel, which needs to be painted, and antiweather steel, the latter involves a higher initial cost. However, from a long term point of view, the total cost, including maintenance costs for the latter will be less after 10 years, as future maintenance costs will be cheaper. To meet the maintenance-free project requirement, antiweather H-shaped steel girders will be used.

Antiweather steel rusts a little in the open air. The formed rust produces a fine rust film on the steel surface that prevents further air contact with the steel and delays the rusting process. Antiweather steel is a low steel alloy which is made of raw steel mixed with copper, chrome, phosphorus, nickel, etc.

2) Substructure

There are different types of substructure: wall type, Rhamen structure, multi-column type, etc.. In this project, the wall type will be employed because of its small impediment, short construction time, and the lack of support work necessary

3) Foundation

Due to the bearing ground depth, the possible foundation types are: open foundation, piling work, or caisson foundation. From these, the open foundation type will be proposed, since boulders with diameters of 20-60 cm are everywhere and a bearing capacity of more than 25 ton/m^2 can be expected, according to the results of a soil survey (load test and test pit survey) around the proposed bridge site.

4) Access Road

Design of the access road will conform with the Road Construction Manual (RCM), Public Works Department, Bhutan. The longitudinal gradient of the road will be set at 6 %. The project will cover three areas: to the intersection with the national highway, a span of 52.0 m where the national highway was raised 1.0 m, which can be recovered with a gradient of 6 % on the right bank side, and to the existing access road, about 75 m on the left bank side.

The access road will be supported by masonry walls on both sides. Pavement will comprise the whole width: 7.5 m on the right bank side and 7.5 m to 5.0 m at the existing road on the left bank side. The intersection on the right will be supported by wall with a 10 m radius. The composition of the pavement will be based on RCM: a 5 cm asphalt concrete surface, a 20 cm crushed stone base, and a 25 cm sandy gravel surface.

5.2.4 Basic Design Drawings

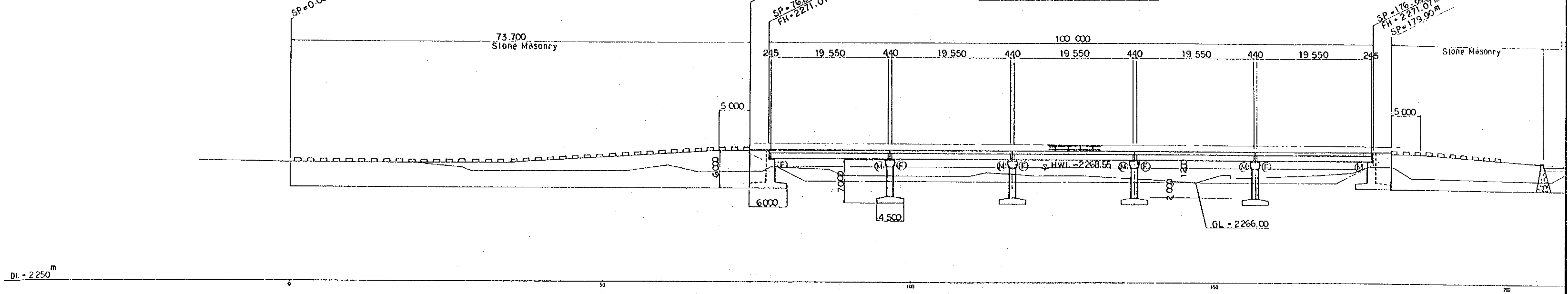
Basic Design Drawings are shown in the following pages.

5.2.5 Work Quantities

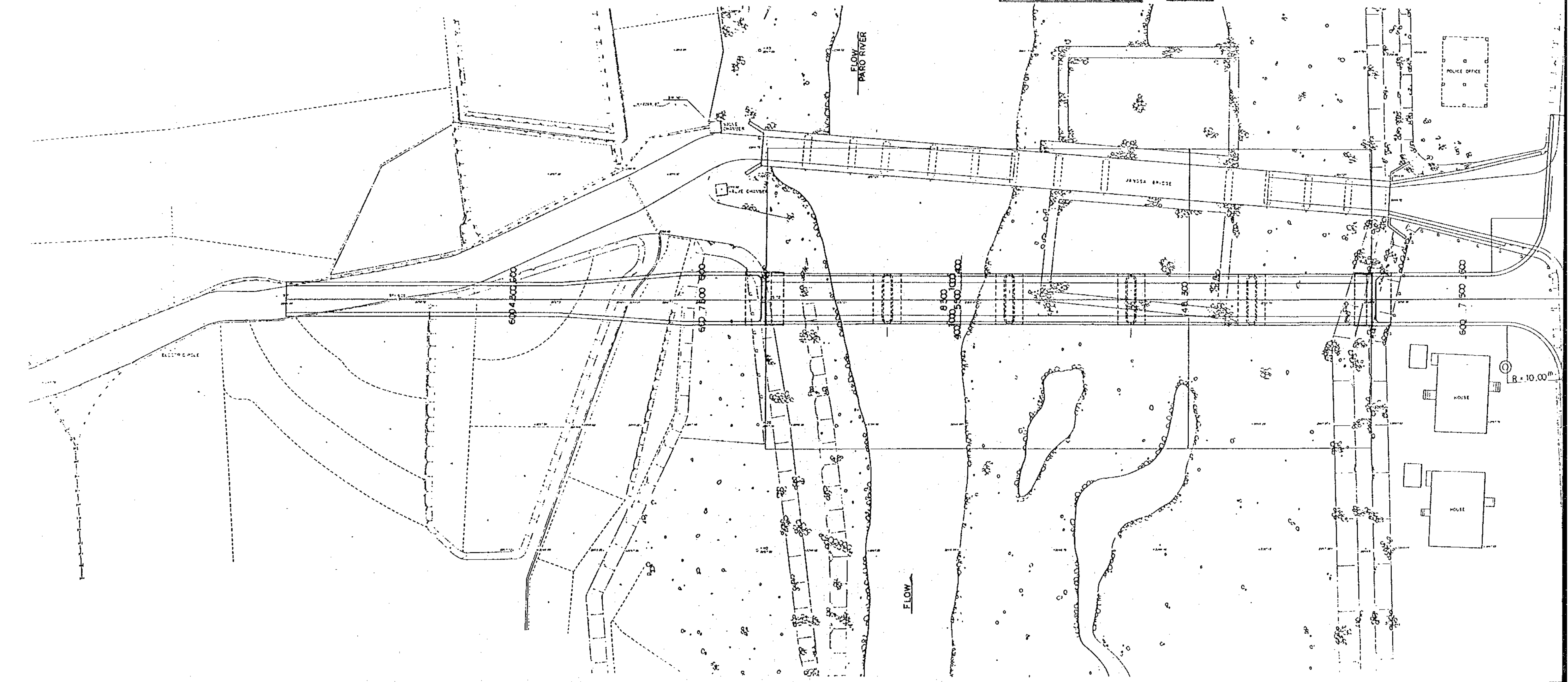
Based on the basic design drawings, the quantities of the bridge work planned are outlined below.

- Superstructure	:	(100 m length) x (7.5 m width), Steel materials = 310 ton Concrete = 600 m^3
- Substructure	:	2 abutments and 4 piers Steel materials = 30 ton Concrete = 600 m^3
- Riverbed protection work	:	(20 m) x (90 m) x (2 m)
- Access roads	:	52 m on the right bank side, and 75 m on the left bank site

GENERAL ELEVATION S=1:300



GENERAL PLAN S=1:300



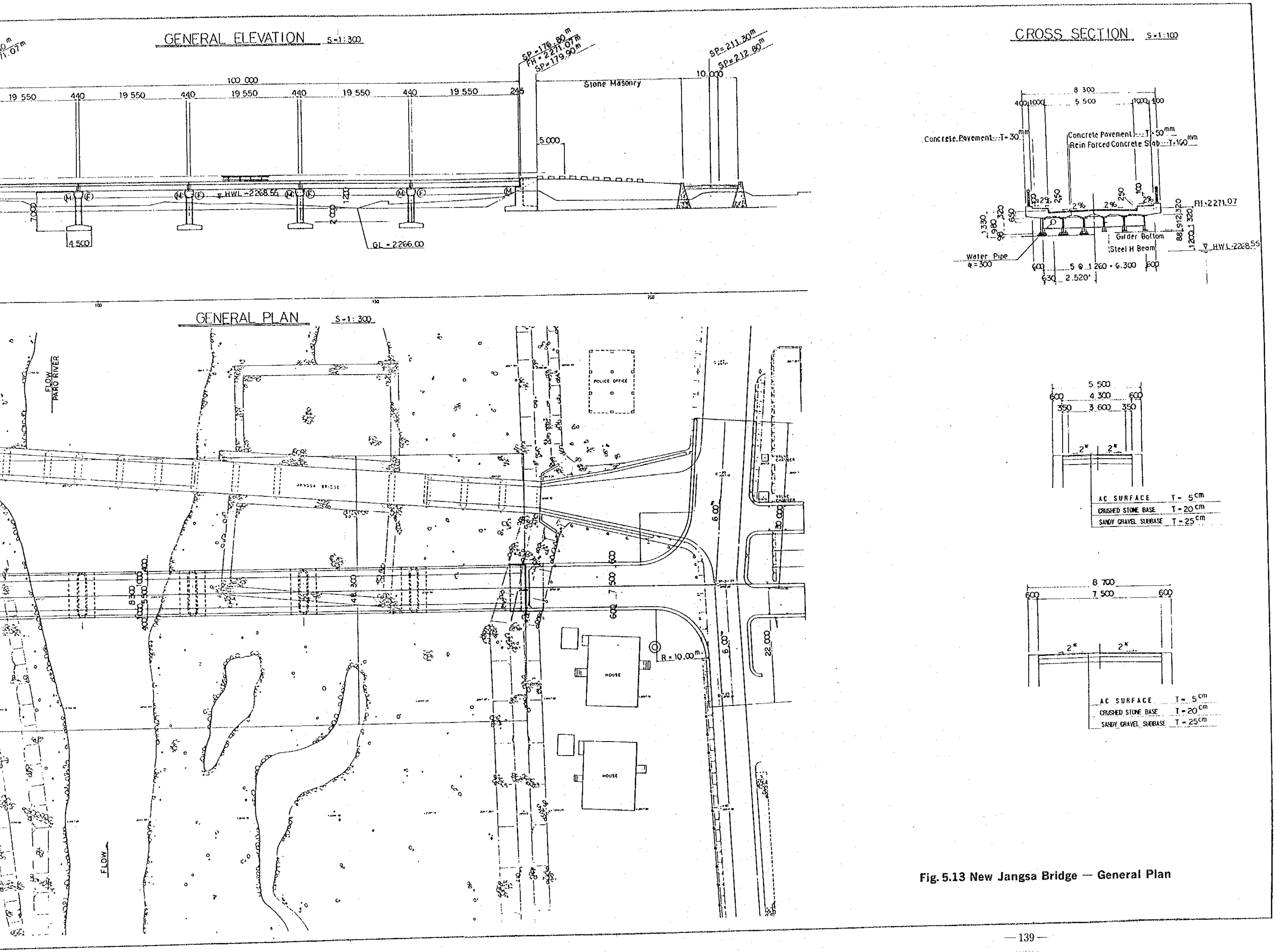


Fig. 5.13 New Jangsa Bridge — General Plan

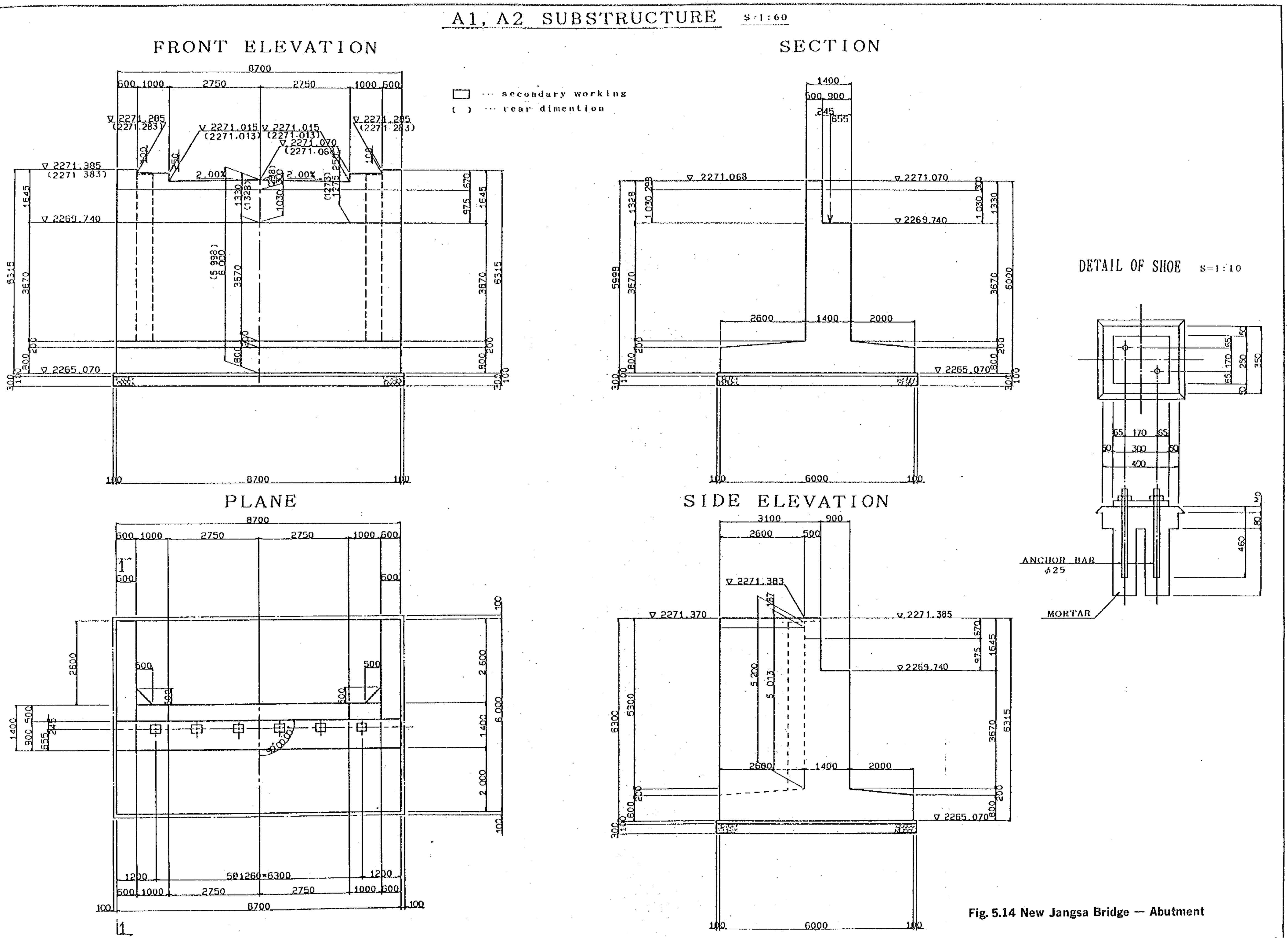


Fig. 5.14 New Jangsa Bridge — Abutment

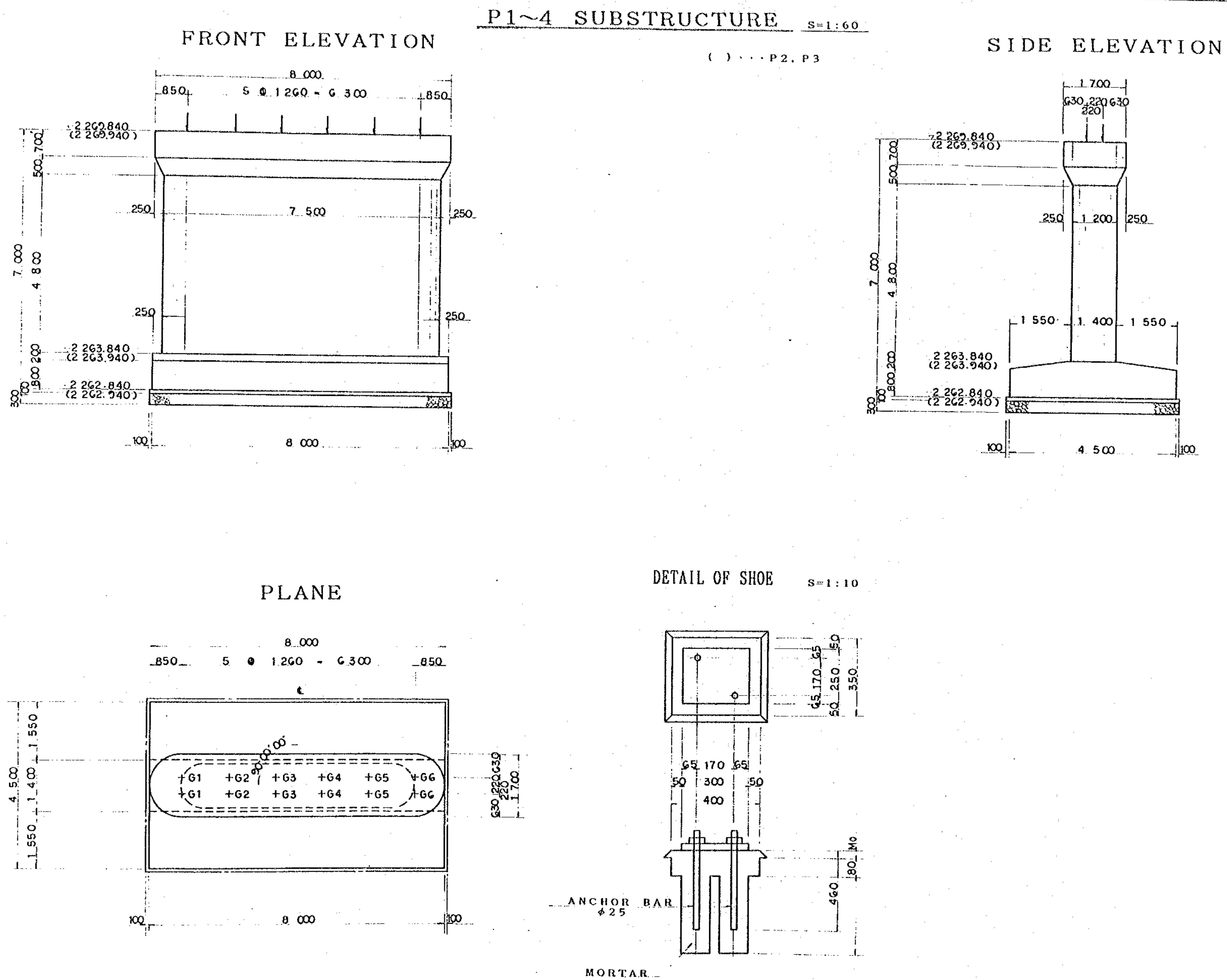


Fig. 5.15 New Jangsa Bridge — Pier