CHAPTER 7

RESULTS OF NATURAL CONDITION SURVEYS AND HYDROLOGICAL ANALYSES

Chapter 7 Results of Natural Condition Surveys and Hydrological Analyses

7.1 Results of Natural Condition Surveys

7.1.1 Topographical Survey

The Study Team carried out a topographical survey for areas described below and shown in Figure 7-1.

a) Section A

A land survey was carried out in this section.

The average ground level of this section is approximately 48.3 m (elevation). The distance between the road and railway ranges from 16 m to 110 m. The intersection of the M1 route with the S151 route has already been upgraded and approximately 140 m of the S151 route from the roundabout has also been upgraded as a paved road.

b) Section B

A land survey, a centre line and cross section survey for the existing road and railway line, and a river cross section survey for the Chiromo washaway section were carried out in this section.

The average ground level of this section is approximately 46.7 m. The distance between the road and railway ranges from 16 m to 110 m. The length of embankment lost due to flooding is approximately 80 m for the road and 350 m for the railway.

c) Section C

A land survey, and a centre line and cross section survey for the existing road and railway line were carried out in this section.

The average ground level of this section is approximately 46.7 m. The distance between the road and railway is 100 m as they are parallel. There is a wetland.

d) Section D

A land survey, a centre line and cross section survey for the existing road and railway line, and a river cross section survey for the Shire River were carried out in this section.

The average ground level of this section is approximately 47.2 m. There is a combined road and railway bridge over the Shire River.

e) Section E

A land survey was carried out in this section.

The average ground level of this section is approximately 48.4 m. The distance between the road and railway ranges from 100 m to 380 m. There is a grave site and an irrigation facility.

f) Section F

A land survey was carried out in this section.

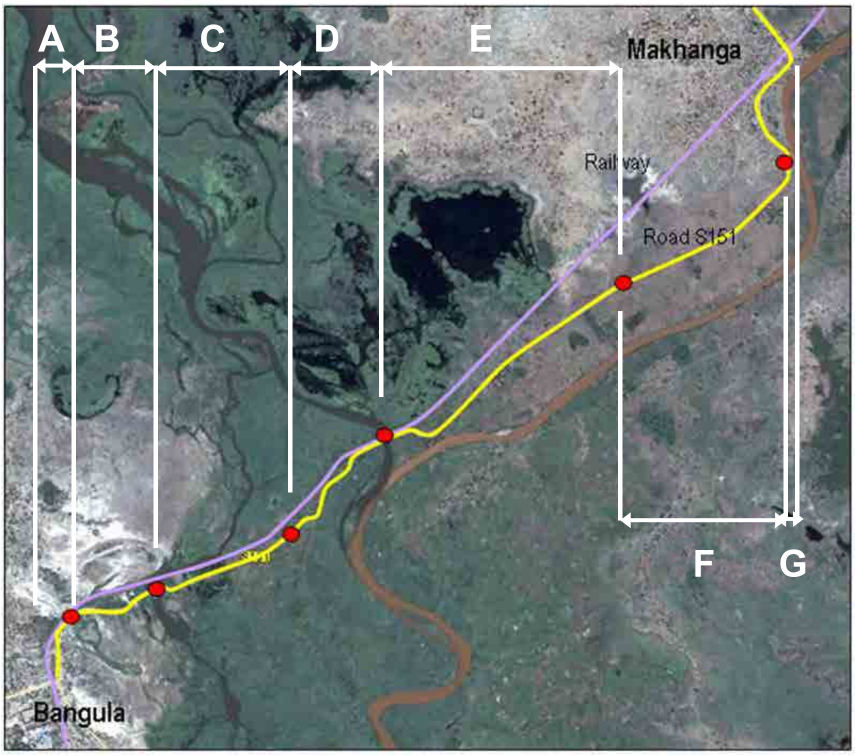
The average ground level of this section is approximately 50.1 m. The distance between the road and railway ranges from 380 m to 730 m. The S151 approaches up to 30 m from the Ruo

River.

g) Section G

A land survey was carried out in this section.

The average ground level of this section is approximately 52.4 m. There is a level crossing where the road crosses the railway, and there is a village market around the level crossing.



Source: Study Team

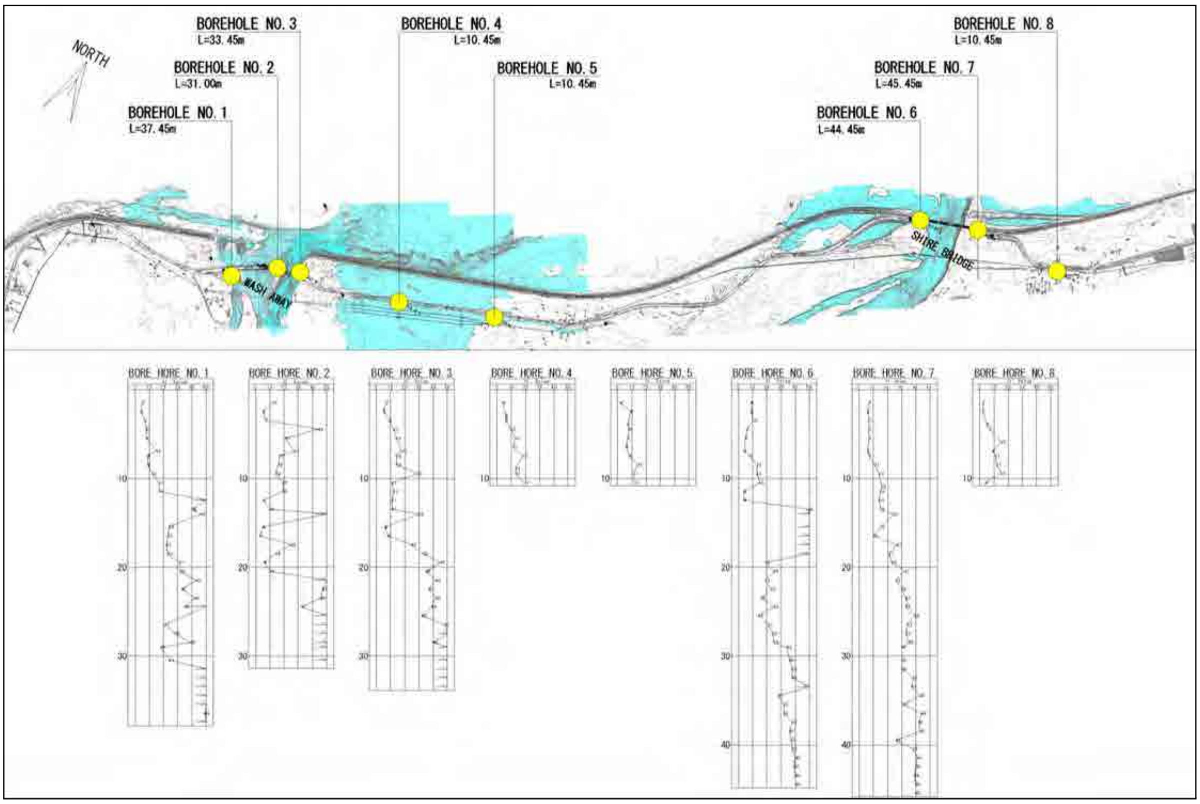
Figure 7-1 Topographical Survey Area and Sections

7.1.2 Geotechnical Investigation

The Study Team carried out the geotechnical investigation by boring at 8 boreholes (BH), shown in Figure 7-2, in order to identify the condition of soil layers where bridge foundations and road embankments are to be constructed as planned in the Study.

a) Both Sides of the Chiromo Washaway Section (BH-1, BH-2 and BH-3)

- There is a bearing layer with an N-value of more than 50 which is 25 m below ground level.
- The bearing layer at BH-1 is identified as silty clay, and those at BH-2 and BH-3 are identified as fine sand. Thus, it is considered that the bearing layer is not uniform on both sides of the New Shire River.
- At the detailed design stage, it is required to conduct additional boring surveys to investigate the soil conditions at the exact points of the planned bridge substructure, and then a bearing layer should be identified.



Source: Study Team

Figure 7-2 Location of Boreholes and Boring Logs

b) Existing Road between the Chiromo Washaway Section and the Kamuzu Truss Bridge (BH-4 and BH-5)

The top 1.45-m layer is composed of silty sandy gravel (fill material). From 1.45 m down to 6.00 m, there is a layer of sandy silty clay. It is considered that this sandy silty clay layer would not require soft soil measures because its N-value is 10.

c) Both Sides of the Kamuzu Truss Bridge (BH-6 and BH-7)

- There is a layer with an N-value of more than 50 extending from 13.45 m to 18.45 m at BH-6. However, the soil layer changes below 19.45 m and its N-value is approximately 20.
- Looking at the results of BH-7, there is no layer within 45 m from ground level which has an N-value of more than 50.
- It is considered that the bearing layer is not uniform on both sides of New Shire River. At the detailed design stage, it is required to conduct additional boring surveys to investigate the soil conditions at the exact points of the planned bridge substructure, and then a bearing layer should be identified.
- Regarding the silty sand layer from ground level down to 6.00 m at BH-6, soft soil measures may need to be taken because the N-value is less than 10. An additional boring survey will be required at the detailed design stage to investigate the soil conditions in detail. If it is found that soft soil measures need to be taken, the stability of the designed embankment should be considered.

d) At the eastern side of the Kamuzu Truss Bridge (BH-8)

The top 2.45-m layer is composed of sandy clay silt with an N-value of 2, for which soft soil measures will need to be taken. There is silty medium coarse sand from 2.45 m down to 5.45 m with an N-value of around 5, so soft soil measures may need to be taken. An additional boring survey will be required at the detailed design stage to investigate the soil conditions in detail. If it is found that soft soil measures need to be taken, the stability of the designed embankment should be considered.

7.1.3 Hydrological Data

The Study Team collected the following hydrological data from the hydrological observation stations of the Ministry of Irrigation and Water Resources (MoIWR):

a) Data of the Shire River at the Chiromo observation station

- Water level data: 39 years from November 1970 to December 2009
- Water discharge data: 39 years from November 1970 to December 2009

b) Data of the Shire River at the Liwonde observation station

- Water discharge data: 12 years from November 1999 to April 2010

There have been no hydrological observations for the Chiromo washaway since it occurred in 1997. A water gauge was installed by the MoIWR on the upstream side of the road embankment in 2008 and used to measure the water level. However, this water gauge was lost due to floods and no water level data is available for the relevant period.

In order to estimate the discharge volume from the survey of current velocity, the Study Team installed two water gauges (one for lower water level and the other for higher water level) beside the road embankment on the Bangula side of the river.

The Study Team also carried current velocity surveys out at both the Chiromo washaway section and near the existing Kamuzu Truss Bridge in order to estimate the discharge volume.

7.2 Results of Hydrological Analyses of the Shire River and Washaway Section

7.2.1 Results of Hydraulic and Hydrological Analyses

Based on collected aerial photos, hydrological data, hydraulic observation data, site investigations and interviews with local residents, the hydraulic conditions of the Shire River, the New Shire River and the Ruo River have been analysed.

(1) Conditions of Rivers

a) Shire River

1) Outline of Basin

The Shire River originates from the Lake Malawi and is the longest river in the country. Its basin consists of various rivers not only in Malawi, but also in Tanzania and Mozambique, and the catchment area of the Kamuzu Truss Bridge is about 149,500 km^2. The river flows from the southern edge of the Great Rift Valley at Lake Malawi and passes through Lake Malombe. The gradient becomes steep near Liwonde, passing through three hydropower stations. It gathers many tributaries and flows in the middle of wide marshes, such as the Elephant Marsh with a gentle gradient, and joins the large left tributary, the Ruo River. About 8 km further downstream, it then joins the right tributary, the New Shire River, and finally joins the large Zambezi River in Mozambique and flows into the Indian Ocean.

2) River Discharge Volume

The Shire River constantly flows from Lake Malawi, bringing large quantities of water to the marshes upstream of Kamuzu Truss Bridge. The average annual discharge volume is 620 m^3/sec, while the average monthly discharge volume in the rainy season is 910 m^3/sec and the minimum monthly discharge volume in the dry season is 264 m^3/sec.

According to the data for the last 39 years, the maximum daily discharge volume is observed in the rainy season between January and March, with volumes of just under 1,200 m^3/sec.

3) Confluence with the Ruo River

The Shire River merges with the Ruo River downstream of Kamuzu Truss Bridge at Chiromo. When the Ruo River becomes full during the rainy season, it easily floods near the confluence due to insufficient discharge capacity. This flood caused by the Ruo River spreads into the flood plain and increases the water level at the confluence. This causes backflow of the Shire River, with the water flowing into the marshes.

This backward flow on the Shire River continues for as long as the Ruo River is full and the water level of the marshes of the Shire River is high. When the overflow of the Ruo River is almost complete, the water level at the confluence decreases and the current of the Shire River returns to normal flow.

4) Marsh of the Shire River

The Shire River enters a wide marsh, called Elephant Marsh, near Chikwawa. The catchment areas of most rivers flowing into the marsh from the north-eastern and western mountain ranges are small with limited rainfall. The total discharge volume is therefore limited for a short period.

However, since the New Shire River was formed at the washaway section and it is now possible for water to accumulate, a clear river line was formed for a wadi from the western Bangula side. It is assumed that water in this wadi during the rainy season gently flowed into the very wet marsh on the surface and did not form a clear river line.

b) New Shire River

1) Upstream of the Chiromo Washaway Section

The New Shire River separates from the Shire River about 2 km upstream of the Kamuzu Truss Bridge, flows toward the railway embankment at an angle of about 45 degrees, flows along the embankment, and then changes direction by almost 90º and flows into the washaway section.

The width of the river at the washaway section is almost 90 m on average during the dry season, and even though the water depth on the right side of the marsh is shallow, the water on the left side of the river quickly becomes deep, reaching about 5 m.

2) Chiromo Washaway Section

At the Chiromo washaway section, the railway embankment was washed away for about 300 m in length. The lower part of the embankment on the Bangula side has not been scoured and this part appears during the dry season. On the other hand, the edge of the railway embankment on the left side of the river has been severely scoured.

The distance between the edge of the remaining road on the Bangula side and the slope used as the landing point for boats is about 60 m in the dry season and 90 m in the rainy season. The river cross section is almost V-shaped and the water depth at the centre is 5 m in the dry season, while the deepest part is almost 10 m. Since there is continuous flow of water even in the dry season, this part of the river does not dry up.

3) Downstream of the Washaway Section

After passing the narrow part by the edge of the remaining road from Bangula, the width of the river is about 200 m and the average water depth is 4–5 m. The deepest part is about 10 m, except where there are islands within the river basin. The New Shire River then flows in the marsh downstream of the washaway section and reaches the confluence with the Shire River about 8 km from the washaway section.

At the confluence, the flow line which discharges the water of the New Shire River is clear and the same quantity of discharge volume flows, since there is no major obstacle in the marsh. As a result, there is no problem of discharge capacity of the New Shire River, which smoothly flows even during floods.

c) Ruo River

The Ruo River flows along the border between Malawi and Mozambique. The origin of the Ruo River is Mount Mulanje which has heavy precipitation, causing a large water discharge volume in the rainy season. It flows in a V-shaped valley in the mountainous section and the gradient of the riverbed is steep, so the flow is fast and contains mud and sand. The catchment area at the confluence is 4,530 km^2.

The riverbed gradient becomes gentle near Makhanga where the terrain is flat and large quantities of deposits remain in the river. The Ruo River merges with the Shire River after the flowing capacity drastically decreases. At this section, the width of the river is about 200 m and the river meanders in the sandbank.

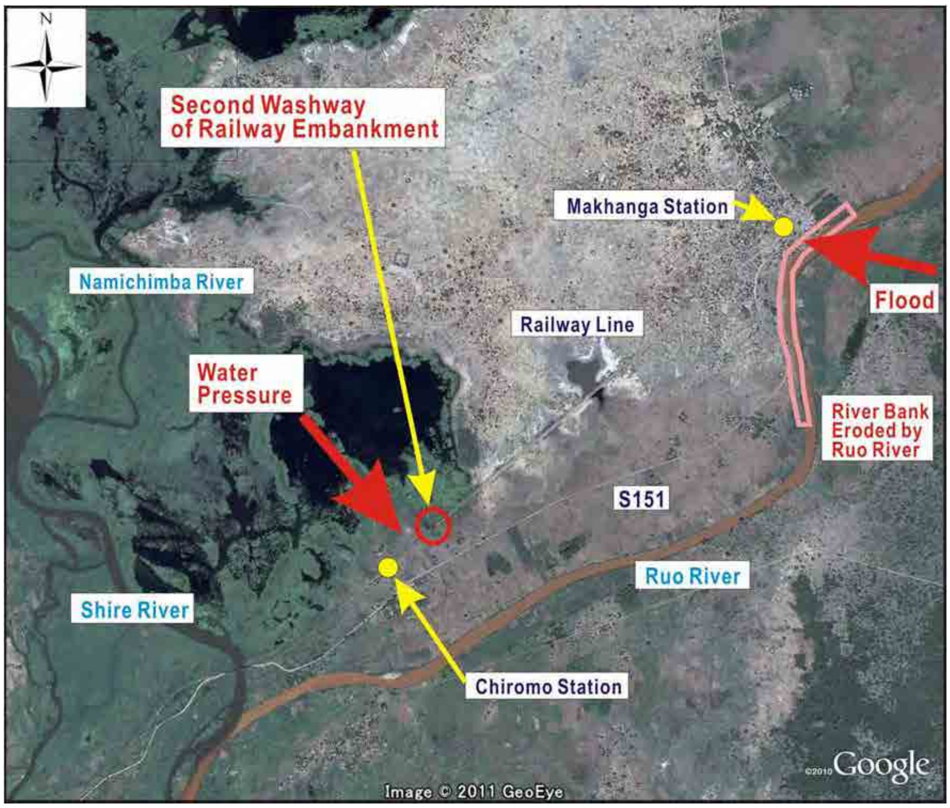
At the confluence with the Shire River, the river width is about 80 m and the height of the low water channel is about 3–4 m with very limited water flow during the dry season. Assuming the current velocity is 5 m/s, the discharge capacity is estimated at about 1,600 m^3/sec. Since several floods with discharge volume exceeding 2,000 m^3/sec have been recorded in the past, it is assumed that floods often occur.

The populated area of Makhanga is located on the natural embankment formed by the Ruo

River and is very close to the right bank of the river. Since the Ruo River starts flooding where the terrain changes from mountainous to flat with siltation problems, parts of Makhanga where the natural embankment is not well formed are often flooded. According to interviews with local residents, the lower area near the market is often flooded up to the foundations of houses. In the past, the whole area including the railway line, which is located on the highest ground, was covered by flood water. When the Ruo River floods, S151 is also inundated and becomes impassable for some time. In addition, erosion of the Ruo River bank near Makhanga is a serious problem. In order to prevent flooding in Makhanga, suitable protection measures should be studied under the comprehensive flood control study, in coordination with the GoMZ, since the Ruo River is a border river.

The Chiromo area, including Chiromo railway station, is also often flooded. This is caused by water coming from the Namichimba River affected by backwater of the Shire River, which forms a marsh on the northern side of the railway embankment. The flood water of Namichimba River also washed away a part of the railway embankment at the 77.5 km post (so-called "second washway"), about 500 m north-east of Chiromo Station.

Figure 7-3 shows the problems of flood and erosion between Makhanga and Chiromo.



Source: Study Team

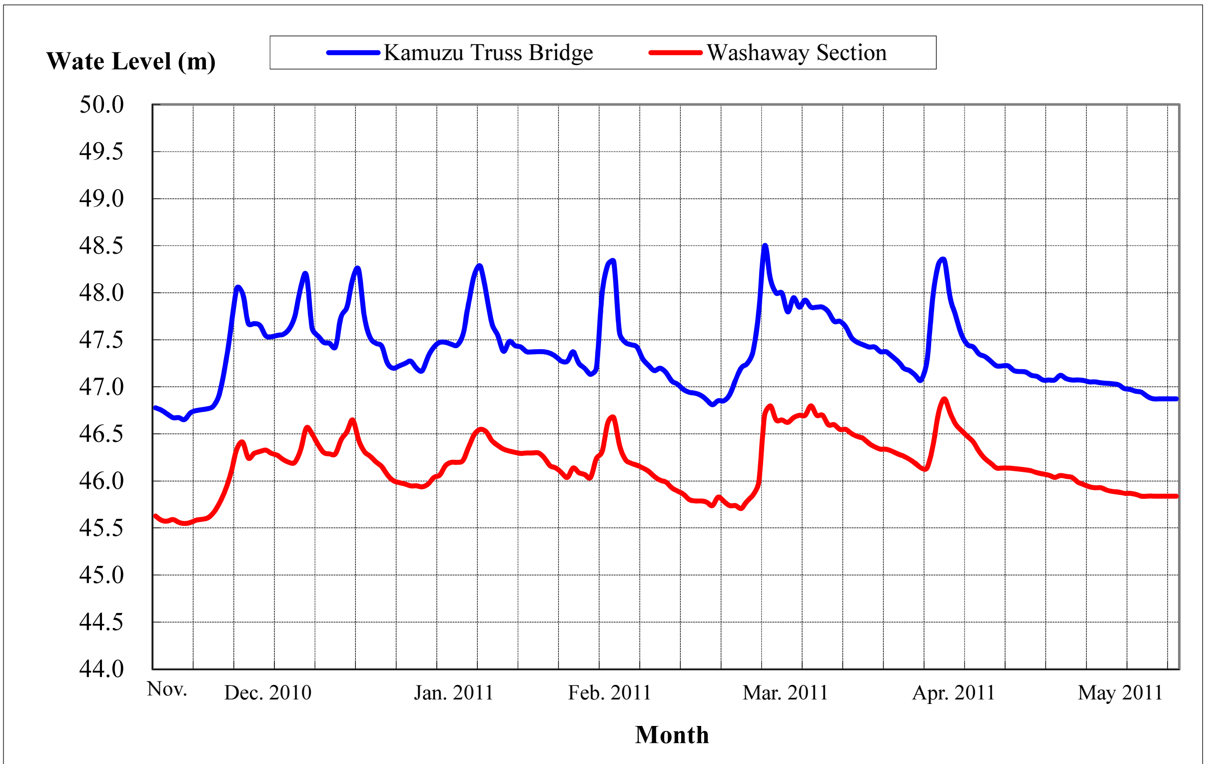
Figure 7-3 Problems of Flood and Erosion between Makhanga and Chiromo

(2) Water Level

According to interviews with local residents, the highest water level at the Chiromo washaway section reached the surface of the remaining road on the Bangula side, so it is necessary to clarify the water level during the rainy season. The Study Team installed two sets of water gauges in order to estimate the discharge volume, and the water level has been measured continuously since 26th November, 2010.

a) Water Level of the Shire River and the New Shire River

When the confluence of the Shire River is overflowed due to flooding of the Ruo River, the main flow of the Shire River is likely to be disturbed and floodwater flows into the marsh; this causes the water level in the whole area to increase. Therefore, the water level of the New Shire River on its own without the Shire River could increase when the Ruo River is flooded. In order to investigate the relationship between these two rivers, the Study Team carried out hydraulic analyses. Fluctuations of water levels (elevation) at the Kamuzu Truss Bridge and the washaway section are shown in Figure 7-4 for two and a half months between November 2010 and May 2011.



Source: Water gauge measurement carried out by the Study Team

Figure 7-4 Fluctuation of Water Level at Kamuzu Truss Bridge and the Washaway Section between November 2010 and February 2011

The general correlation between the water level at Kamuzu Truss Bridge and at the washaway section is as follows:

- Small-scale floods have occurred seven times on the Ruo River with highest water level on 11th March, 2011.
- Water level curves at Kamuzu Truss Bridge and the washaway section show similar tendencies and water levels at both locations are considered to have a correlation.

- The water level at Kamuzu Truss Bridge fluctuates between 46.7 m and 48.5 m, while the water level at the washaway section is lower between 45.5 m and 46.9m.
- Difference of water levels at both observation points are between 0.9 m and 1.8 m, and the average is 1.2 m.

As a result, it can make hydrological analyses at the washaway section based on the water level observation results at the washaway section.

(3) Water Discharge Volume

Water discharge volumes during the current velocity surveys were estimated based on the cross section of rivers and results of water level measurements, as shown in Tables 7-1 and 7-2.

The water level at Kamuzu Truss Bridge in the dry and rainy season were 5.11 m and 5.70 m, respectively, while those at the washaway section were 0.69 m and 1.25 m, respectively. Therefore, the discharge volumes at Kamuzu Truss Bridge in the dry season and rainy season are estimated at 176 m^3/sec and 276 m^3/sec, respectively, while those at the washaway section are estimated at 96 m^3/sec and 230 m^3/sec, respectively.

Table 7-1 Estimated Water Discharge Volume in the Dry Season

Washaway Section	Side	Timing			Distance	c1	Velocity	Area	Discharge
		min	sec	Sec	m		m/s	m^2	m^3/sec
Bangula	Right	2	29	149	50	0.91	0.31	104.3	29
	Centre	2	1	121	50	0.91	0.38	148.4	51
Chiromo	Left	1	55	115	50	0.91	0.40	44.3	16
						Average	0.36		96
Kamuzu Truss Bridge	**Side**	**Timing**			**Distance**	**c1**	**Velocity**	**Area**	**Discharge**
		min	**sec**	**Sec**	**m**		**m/s**	**m^2**	**m^3/sec**
Makhanga	Right	1	34	94	50	0.91	0.48	101.0	44
	Centre	1	12	72	50	0.91	0.63	145.2	84
Bangula	Left	1	50	110	50	0.91	0.41	128.2	48
						Average	0.51		176

Note: c1 is a coefficient used for estimating flow velocity with a 1 m float, and its value is 0.91.
Source: Current velocity survey carried out by the Study Team

Table 7-2 Estimated Water Discharge Volume in the Rainy Season

Washaway Section	Side	Timing			Distance	c1	Velocity	Area	Discharge
		min	Sec	Sec	m		m/s	m^2	m^3/sec
Bangula	Right	1	27	87	50	0.91	0.52	117.9	62
	Centre	0	57	57	50	0.91	0.80	161.1	129
Chiromo	Left	1	6	66	50	0.91	0.69	57.0	39
						Average	0.67		230
Kamuzu Truss Bridge	**Side**	**Timing**			**Distance**	**c1**	**Velocity**	**Area**	**Discharge**
		min	**Sec**	**Sec**	**m**		**m/s**	**m^2**	**m^3/sec**
Makhanga	Right	1	16	76	50	0.91	0.60	114.8	69
	Centre	0	57	57	50	0.91	0.80	158.0	126
Bangula	Left	1	20	80	50	0.91	0.57	141.8	81
						Average	0.66		276

Note: c1 is a coefficient used for estimating flow velocity with a 1-m float, and its value is 0.91.
Source: Current velocity survey carried out by the Study Team

(4) Estimation of Water Discharge Volume and Water Level in the Chiromo Washaway

Hydrological volumes in the Chiromo Area are estimated based on the existing hydrological observation records (discharge volume for the last 39 years and water level for the last 39 years), results of current velocity surveys and water level measurements (see Figure 7-5).

a) Kamuzu Truss Bridge

According to the existing observation data, the past maximum discharge volume did not exceed 1,500 m^3/sec, while the past maximum water level was recorded as 49.599 m in 2005. Before 1997 when the washaway occurred, the maximum water level was between 47.1 m and 48.5 m. However, after 1997, the maximum water level exceeded 49.0 m almost every year.

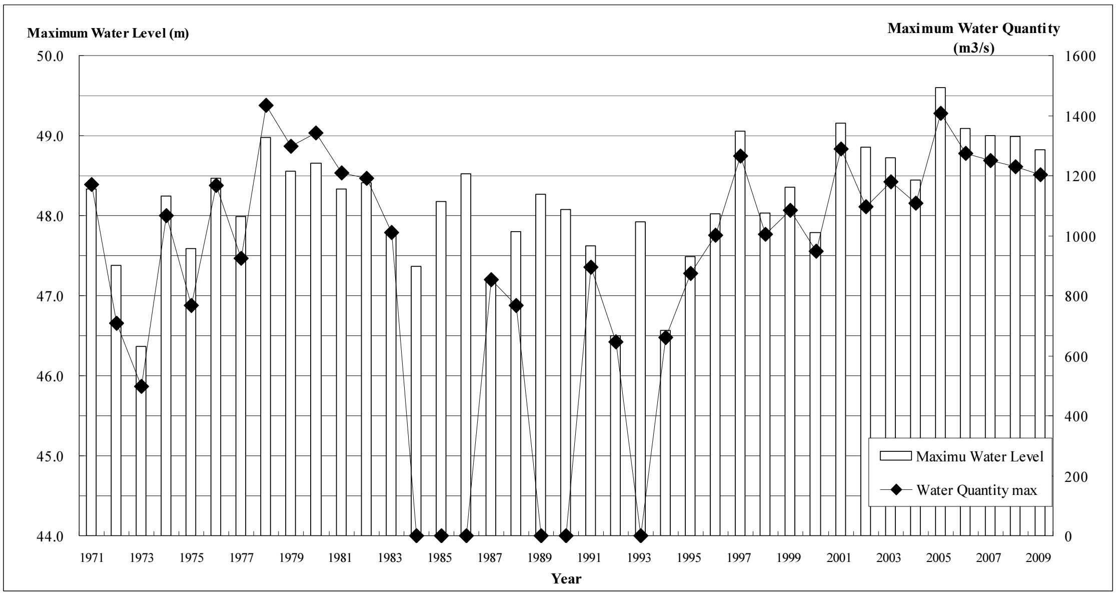
b) New Shire River

Even though there is no existing observation data of discharge volume, it is possible to estimate the water level and discharge volume based on the results of water level measurements since November 2010 and existing hydrological data at Kamuzu Truss Bridge for the last 39 years.

c) Water Level

Since the water level at the washaway section is estimated by correlation with the water level at Kamuzu Truss Bridge, based on limited observation records, the highest water level during floods can be estimated by referring to the water level at Kamuzu Truss Bridge.

According to the results of analyses, difference of water levels at the washaway section and Kamuzu Truss Bridge is between 0.9 m and 1.8 m (lower at the washaway section), and the average difference is 1.2 m.



Source: MoIWR

Figure 7-5 Annual Maximum Water Level and Maximum Water Quantity at Kamuzu Truss Bridge

d) Water Discharge Volume

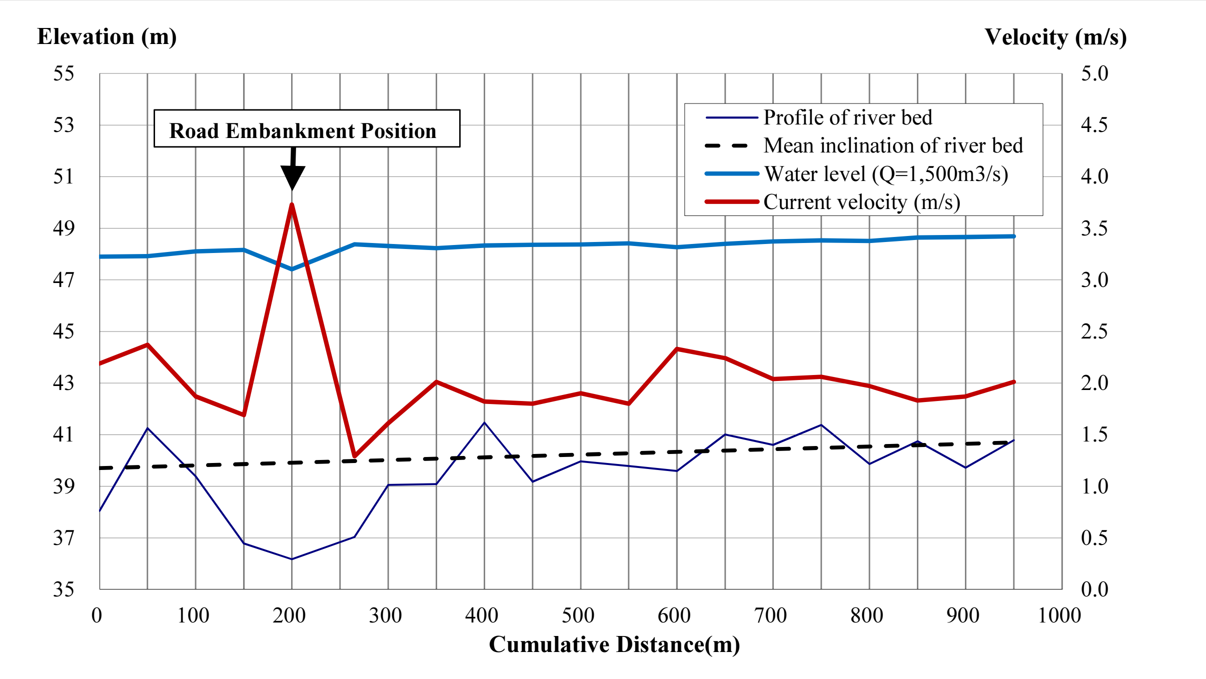
Since the past maximum discharge volume did not exceed 1,500 m^3/sec and the floods on the Ruo River continue for a long time, the planned maximum discharge volume as a peak discharge volume can be considered to be the same as the maximum discharge volume at Kamuzu Truss Bridge.

Based on the analysis results described above, the planned HWL during flooding at the washaway section is estimated as 48.4 m.

7.2.2 Estimation of Condition of the New Shire River Section

The Study Team carried out topographical surveys around the New Shire River and identified the present conditions of river sections both upstream and downstream of the washaway section. The Study Team then carried out hydrological analyses of the water discharge situation of the Shire River during a flood, and estimated the maximum discharge volume of 1,500 m^3/s with HWL of 48.4 m during the flood. The conditions of the existing river section are identified based on the estimated water level and current velocity.

Figure 7-6 illustrates the present water level during a flood, the profile of the river bed, the mean inclination of the river bed, and the flow velocity of the New Shire River around the Chiromo washaway section. The water level is estimated for the following conditions:



Source: Study Team

Figure 7-6 Present Water Level of the New Shire River at the Washaway Section

(1) Section for the Estimation

The estimation covers the section from 200 m downstream of the existing embankment of the road at the Chiromo washaway section to the location where the New Shire River starts to flow along the existing railway embankment, with a total length of 950 m.

(2) Width of River

The New Shire River was formed after the railway embankment was washed away in 1997. Water now flows continuously during both the dry season and the rainy season, and the river course has become clear.

During a flood, the water level rises because of the increased discharge volume which is discharged by a wider river width than the normal situation, if there is no obstacle that limits an increase in river width. However, if any obstacle stops the river from becoming wider, the water level at the upstream increases due to insufficient discharge capacity of the river section, and the increased flow velocity causes scouring of the river section which is formed by sedimentation of soil. Therefore, it is necessary to confirm the existence of any obstacles that would prevent an increase of river width for the sections of the New Shire River that do not usually have any problem, in order to estimate the river width during a flood.

a) Course of the River Section

Normally, the New Shire River discharges into the very wide and flat Elephant Marsh, flows along the railway embankment at the upstream side, and then changes direction at right angles at the edge of the Chiromo washaway section of the railway embankment and discharges to the downstream side.

b) Restrictions

The present conditions of the following three river sections, where hydraulic restrictions might occur during a flood of the New Shire River, are analysed.

1) Upper-most section of the New Shire River

The New Shire River, which has separated from the right bank of the Shire River, discharges freely in the marsh when the water level rises, since there are no topographical restrictions.

2) Section between Upstream and the Edge of Collapsed Railway Embankment

The New Shire River is forced to discharge along the railway embankment in this section. At times of low water level, it discharges only at the foot of the railway embankment, and the river can become wider toward the marsh side, as there are no restrictions on widening of the flow.

3) Section between the Edge of Collapsed Railway Embankment and Downstream

The width of the New Shire River is first controlled by collapsed railway embankments on both sides of the washaway section (width of about 300 m), then further controlled by a road embankment on the Bangula side located just downstream from the railway embankment. After this section, water discharges freely towards the downstream following the river route of the river section formed by the major washaway.

c) River Width during a Flood

Based on the results of analysing hydraulic restrictions for the river section of the New Shire River during a flood, hydraulic restrictions to the discharge of flood water were identified at two river sections in the section between the edge of the collapsed railway embankment and downstream.

Within these two narrow river width sections, the narrowest section is related to the road embankment on the Bangula side, and spot-scouring of river sections as well as collapse of embankment are considered, because the flow from upstream to downstream is highly restricted during a flood. This road embankment was built together with three box culverts in December 2004, in order to connect the washaway section after the major collapse of the railway embankment in 1997. This road embankment will be a useless structure after a new bridge is constructed.

Therefore, it is estimated that water discharges over a width of about 200 m during a flood, in view of the area of railway embankment collision and river section, assuming that the road embankment does not exist.

(3) Condition of River Section and Inclination of River Bed

The deepest elevation of the river bed along the railway embankment is estimated to be between 39 m and 41 m without local deep scouring of the river bed, based on the cross section of the river section of the New Shire River. However, from the edge of the collapsed railway embankment with almost a right-angled bend, the river bed is deeply scoured and it is deepest with 36 m at the river section where the road embankment exists. After this river section, the river bed returns to 39 m to 41 m elevation without local deep scouring of the river bed. The main cause of this deep erosion is considered to be the river section with a narrow channel. The average river bed grade is estimated as 1/950, except at the deepest river bed section.

(4) Downstream Water Level

The downstream water level of elevation 47.9 m with a design discharge volume of 1,500 m^3/s is used for estimating the river section of the New Shire River. This water level is calculated under the condition of uniform flow on the average river bed grade.

(5) Roughness Coefficient in the River Section

The roughness coefficient of a river section means the resistance to discharge of river flow, and its value is determined by conditions such as the shape of the river section, materials of the river bed, vegetation, etc. Experimental values of this roughness coefficient are available as the N-value of Manning's Formula classified according to the conditions of the whole river section.

The Shire River flows into the wide Elephant Marsh and the huge volume of silty material transported from upstream forms the river bed as sedimentation of the materials occurs. The grade of the river channel is gentle, there is no large-scale meandering, and the flow route is almost straight. Therefore, the conditions of "large-scale channel", "sandy river bed", and "channel with limited meandering (n = 0.018 – 0.035)" are considered, and so a roughness coefficient of 0.035 is used for calculation.

(6) Results of Calculation

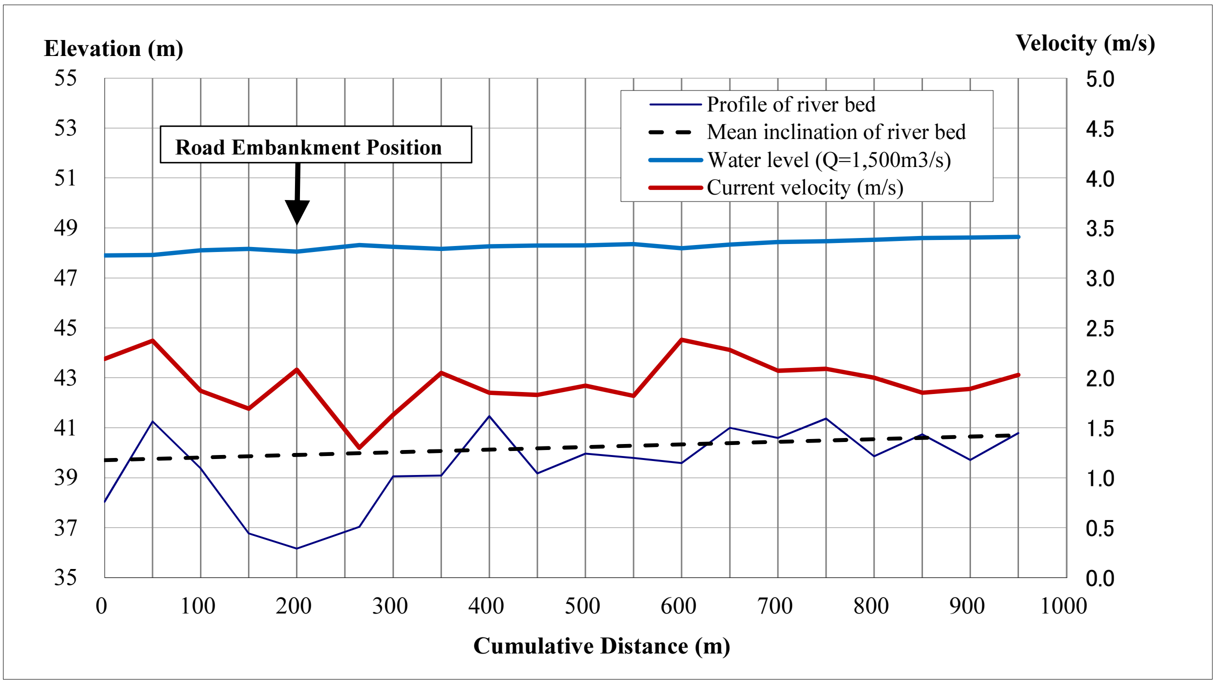
a) Water Level

The design highest water level at the location of the planned bridge sites ranges from 47.4 m to 48.4 m, as shown in Figure 7-7 and below the maximum HWL of 48.4 m. The water level at the narrowed channel caused by the road embankment is 47.4 m, which is 1.0 m below the designed water level, while the water level at the collapsed railway embankment, just upstream, increases to 48.4 m, 1.0 m higher than the narrowed channel section. The water level of the upstream section from the locations of the planned bridges ranges from 48.2 m to 48.7 m and the grade of river surface during a flood is almost the same as the river bed grade with gentle river flow.

b) Current Velocity

The current velocity of the New Shire River during steady flow ranges from 1.3 to 3.7 m/s at the locations of planned bridges and is fastest where the channel section narrows due to the road embankment. The current velocity upstream of the collapsed railway embankment ranges from 1.6 to 2.3 m/s and the river flows gently, except at the narrowed channel section.

The river section of the New Shire River, which discharges into Elephant Marsh, is formed by sedimentation of silty material. When the current velocity increases, fine silty sediment is easily moved by the attractive force of the river flow, and so local scouring of the river section is likely to continue.



Source: Study Team

Figure 7-7 Designed Water Level of the New Shire River at the Chiromo Washaway Section

7.2.3 Plan for Protecting the River Section

The Study Team has considered plans to construct two bridges at the Chiromo washaway section of the New Shire River. Hence, it is desirable to secure a smooth flow of flood water at river sections after constructing these two bridges.

(1) Major Issue

The elevation of the top of the road embankment on the Bangula side is about 49.0 m and the distance between the edge of the road embankment and the boat landing place on the

Makhanga side is very narrow, with only about 60 m. This narrow channel can obstruct water discharge because the current velocity is 3.7 m/s, about twice as fast as the upstream and downstream sides.

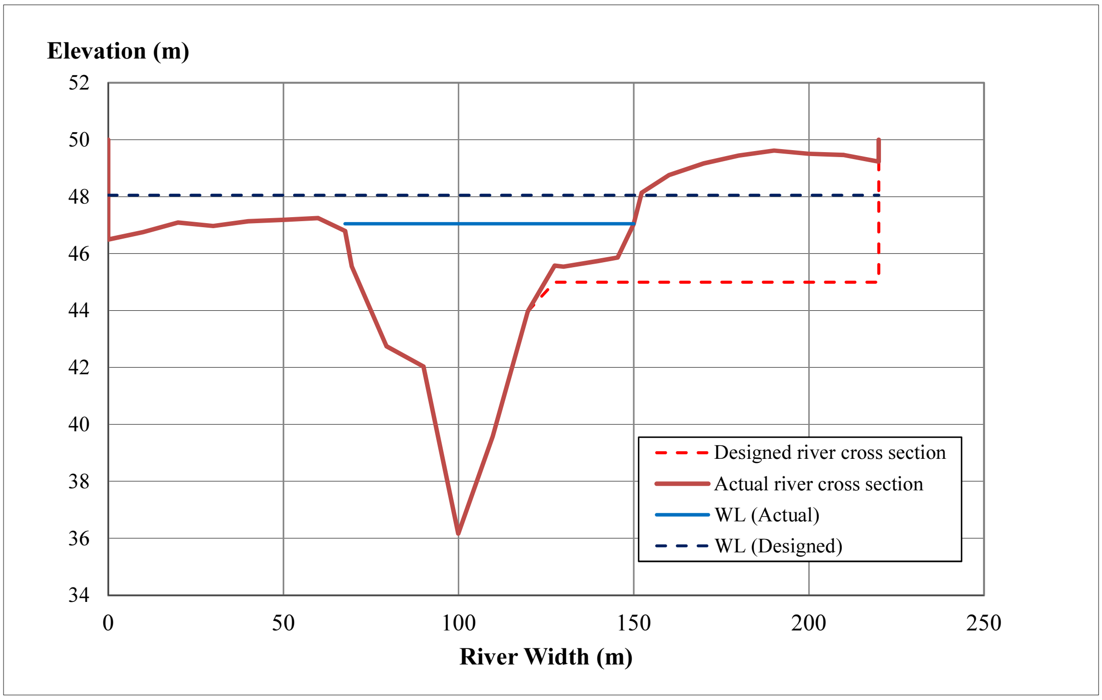
If there is a channel with variations between upstream and downstream of a river, this is a major cause of local scouring at the centre of the river section due to the restricted river width.

If this narrow channel remains in the future, further erosion of the river section will continue and possibly cause the river bank to collapse. Hence, this problem must be solved.

(2) Countermeasures

Based on the results of a hydraulic analysis assuming that the entire road embankment on the Bangula side is demolished and a part of the river section is excavated (see Figure 11-8), the current velocity is estimated to decrease to about 2.0 m/s if sufficient river section is secured with the river bed elevation of about 45.0 m.

In this case, it is necessary to protect the excavated river bed by installing gabions (1×2×0.5 m) to protect the whole excavated area. Also, it is necessary to conduct the minimum-scale improvement of the river section in consideration of the condition of the New Shire River, in order to maintain river sections between newly installed abutments and piers of the planned bridges.



Source: Study Team

Figure 7-8 Plan for Improving the River Section at the Narrowed Channel Section

(3) Plan for Improving the River Section

The New Shire River is characterized by: 1) variation of discharge volume between the rainy season and dry season, and 2) increase of water level in the rainy season caused by the Ruo

River. In general, it is possible to design a river cross section to vary in width according to variations in water quantity. This means that the low flow channel with narrow river width is used to discharge water during the dry season when there is less water, while the river cross section above the high water channel is used to discharge flood water during the rainy season. This approach is called “multiple river cross sections.” In this analysis, a preliminary study was carried out for multiple river cross sections and standard types of revetments.

a) Chiromo Washaway Section

1) River Width

It is estimated that the river width will be about 220 m during a flood after demolishing the road embankment at the narrow channel, with a current velocity of 2 m/s. Since the water level during the normal situation in the rainy season is an elevation of about 46 m, the width of the low flow channel is sufficient within the existing narrow channel of 60 m. Therefore, the high water channel is determined to prevent an increase of excessive current velocity during a flood.

2) River Cross Section

The water level of the New Shire River falls to an elevation of about 45 m during the dry season, increases to 46 m in the rainy season, and increases to 48 m when a flood occurs caused by the Ruo River. The elevation of a high water channel is normally determined to allow inundation several times a year or once every two years with the annual maximum water discharge volume. Based on the records of water level readings at the washaway section, the maximum water level in 2011 was 46.9 m. Hence, the high water channel is set with an elevation of 47 m.

3) Gradient of Embankment Slope

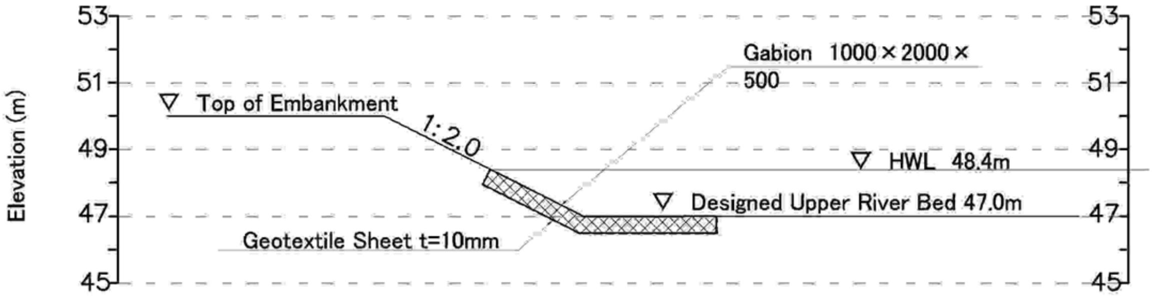
The gradient of the embankment slope is estimated to be 1:2.0.

4) Revetment Works

For structures planned in the Study, revetments for both the low flow channel to protect the low flow channel bank and for the high water channel to protect the embankment at times of HWL are necessary.

i) Revetment for high water channel (Type A)

The river flow will directly affect the abutments and piers of constructed road and railway bridges below the HWL. Even though the current velocity is about 2 m/s, the velocity around structures is not uniform and whirlpools could form. Hence, it is necessary to install minimum revetments using mat-shaped gabions in stepped placing (see Figure 7-9). The area for installing revetments is planned to be about 30 m from the position of an abutment on both sides, as the minimum required to protect the embankment around an abutment. This type of revetment is also planned to be installed beside the piers of bridges to protect against the incoming flow of water to prevent scouring of the foundations of piers, covering an area about three times wider than the side width of piers.

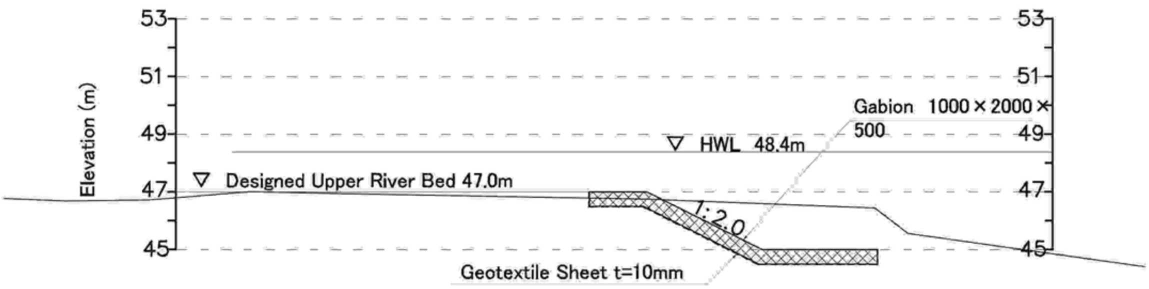


Source: Study Team

Figure 7-9 Typical Cross Section of River Protection Work for the New Shire River (Type A)

ii) Revetment for low flow channel (Type B)

The revetment for the low flow channel is designed to protect the banks of the river when the water level is low. Since the velocity of steady flow is about 2 m/s, it is planned to place mat shaped gabions on flat ground to prevent local scouring at the foot of the river bank. The area over which the revetment is planned to be placed is 100 m from the edge of the abutment on both sides (see Figure 7-10).



Source: Study Team

Figure 7-10 Typical Cross Section of River Protection Work for the New Shire River (Type B)

b) Railway Embankment

1) Width of the River

Since the right side of the New Shire River along the railway embankment is the flat marsh, flood water spreads into the marsh and is discharged with uncontrolled width. The current velocity at this part of the river is about 2 m/s at present. Therefore, flood water is estimated to mainly discharge along the water route with a river width of about 200 m.

2) River cross section

The elevation of the top of the railway embankment is about 50 m and the width of the top of the embankment is about 4.0 m. The slope gradient of the embankment is 1:2.0 and the embankment is stable, except in sections that have been partly scoured.

However, the New Shire River constantly flows along the railway embankment and so the foot of the embankment, which is part of its foundation, is likely to be gradually scoured, because this part of the embankment is part of the river section subject to discharge. Also, the edge of the collapsed embankment has receded towards Makhanga caused by erosion at the edge of the collapsed embankment, because the water route turns almost at right angles at this point.

Since this embankment serves as the bank of the New Shire River, it is necessary to carry out measures, the same as for an ordinary river bank.

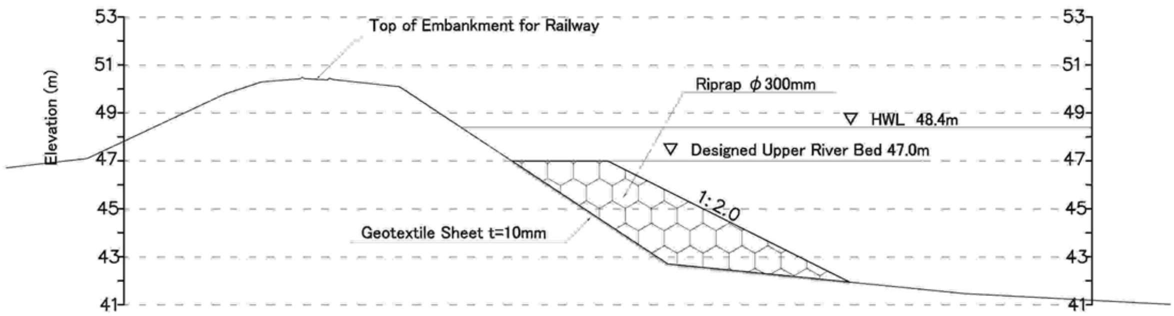
3) Gradient of Railway Embankment Slope

The gradient of the embankment slope is estimated as 1:2.0.

4) Revetment Works (Type C)

Foot protection works are planned to be taken as countermeasures to control scouring of the foot of the railway embankment, which is the right-side bank of the New Shire River. Foot protection works will be performed with revetment by riprap, involving throwing rock material such as round stones into the foot of the embankment up to the high water channel level of elevation of 47 m. The width of the revetment is planned to be about 4 m with a slope gradient of 1:2.0. Round stones are available from those rivers across S152 (see Figure 7-11).

It is planned to apply this foot protection works between the location where the New Shire River collides with the railway embankment and the existing landing point of boats, including the edge of the collapsed railway embankment on the Makhanga side.



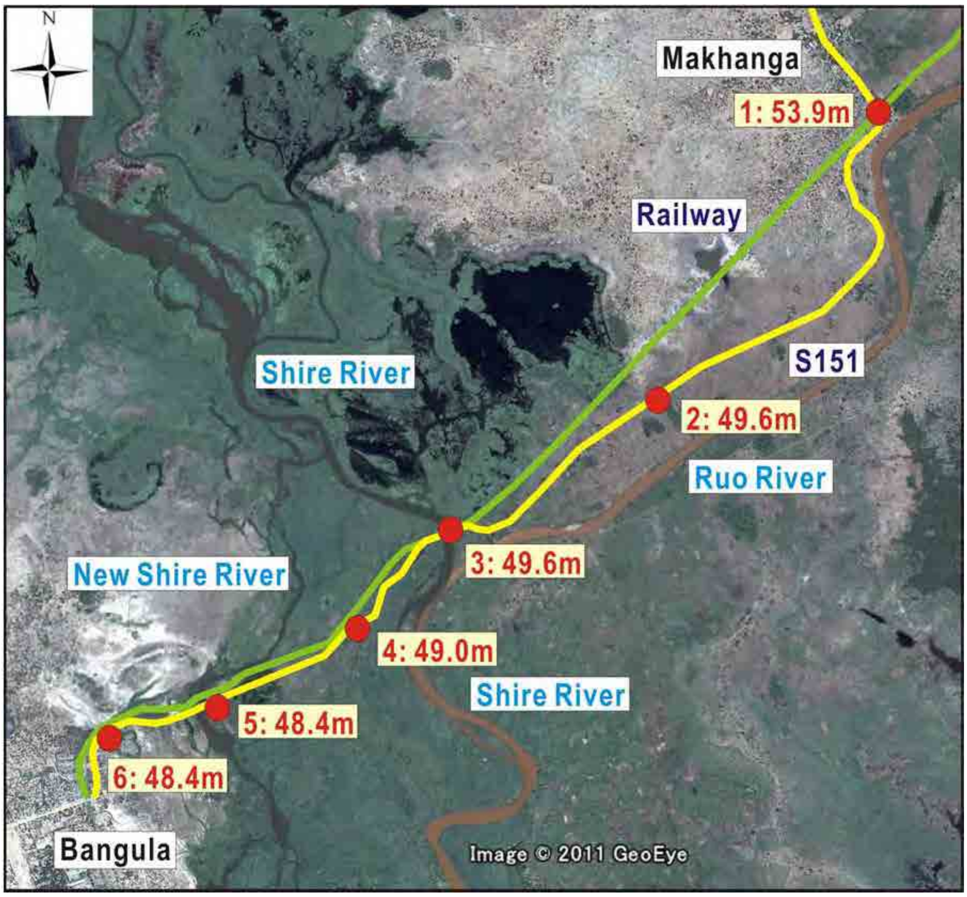
Source: Study Team

Figure 7-11 Typical Cross Section of River Protection Work for the New Shire River (Type C)

7.2.4 Hydraulic Analyses for Road Improvement Plan

In order to identify HWL of the area for the road and railway improvement plans, hydraulic analyses were carried out to determine HWL at certain points along the improvement sections based on records of water gauge readings at the Shire River and the New Shire River. Note that HWL of the section between Makhanga and the Shire River is estimated based on interviews with local residents about their experiences of floods in the past.

Figure 7-12 shows estimated HWL at six points.



Source: Study Team

Figure 7-12 Estimated HWL for the Area between Chiromo Washway and the Makhanga

CHAPTER 8

PRE-FEASIBILITY STUDY ON RECONSTRUCTION OF S151 ROAD BETWEEN MAKHANGA AND BANGULA

Chapter 8 Pre-Feasibility Study on Reconstruction of S151 Road between Makhanga and Bangula

8.1 Justification of Reconstruction of S151 between Makhanga and Bangula

In the Master Plan study, reconstruction of S151 between Makhanga and Bangula was selected as the first priority project in the short- and medium-term programme. Before the major washaway at Chiromo in 1997, there was a paved road between Makhanga and Bangula and vehicles travelling on this road section enabled people to take agricultural products from the western side of the Shire River to the market in Bangula. After the washaway, the road was cut completely and people must now cross the river by boat to take their products to Bangula, which is expensive. This situation has a large negative impact on the local economy and lives of the local residents, particularly those living on the eastern side of the Shire River.

RA has already signed a contract with a contractor to upgrade S151 between Thyolo and Makhanga and construction works are expected to commence soon. After this section of S151 has been upgraded, the arterial road network in the Southern Region will be complete, except for a gap between Makhanga and Bangula. S151 can then serve as an alternative to M1, which is currently the only arterial road connecting the Lower Shire area and Blantyre.

Under these circumstances, the Study Team considers that carrying out the Pre-F/S for the reconstruction of S151 between Makhanga and Bangula is justified.

8.2 Preliminary Design

8.2.1 Preliminary Design of Road Section between Makhanga and Bangula

(1) Upgrading Concept of the Design Road

The S151 Road is one of the routes which form the primary road network in Malawi. From the view point of improving road functions of S151, most important requirements for upgrading concept are to secure safe and reliable traffic throughout the year in accordance with not only the Malawi highway standards but the needs and conditions in the target area. Therefore, the upgrading concept of the S151 Road is to build a two-lane paved road which will not be flooded in the rainy season. The required height of the raised road should be determined considering expected flood levels. The estimated raising height of S151 road is at 2.3 m on average for the total projected extension.

(2) Alignment Selection Process

The Study Team selected the proposed road alignment of the project by dividing it into the following two sections (see Figure 8-1).

- Section A: Outside Makhanga Village (L = 6 km) [3 alternatives]
- Section B: In Makhanga Village (L = 3 km) [3 alternatives]

Source: Study Team

Figure 8-1 Section Map for the Alignment Plan

a) Road Alignment outside Makhanga Village (Section A)

Road alignment should be determined considering various factors such as natural conditions (hydrology, geography, geology, etc.), land use (agriculture, resident, marsh, etc.), infrastructure (road, railway, lifeline, etc.) and living environment (traffic factor, safety, accessibility, landscape, etc.).

The Study Team conducted a comparison of the following three alternatives regarding where the raised road should be built in Section A. As a result of the comparison, Alternative 1 is more advantageous in terms of i) measures for ground stabilization and ii) construction cost. (see Table 8-1)

Alternative 1: Existing Road Alignment

Alternative 2: Between the Existing Road and the Railway Line

Alternative 3: Railway Line Alignment (Integrated Embankment of Road and Railway)

Table 8-1 Road Alignment outside Makhanga Village (Section A)

Section A: Outside Makhanga Village (L = 6 km)						
Alternative	**1**		**2**		**3**	
	Existing Road Alignment		**Between the Existing Road and the Railway Line**		**Railway Line Alignment (Integrated Embankment of Road and Railway)**	
Measures for Ground Stabilization	Slow filling could be required	A	Replacement of top soft soil layer (2m) could be required	D	Replacement of top soft soil layer (2m) could be required	D
Influence on Railway Embankment	No impact	C	No impact	C	Railway embankment could need to be rebuilt due to poor stability	D
Farmland between road and railway	Land use could be partially limited due to road raising	C	Land use could be partially limited due to road raising	C	Keeping the status quo	A
Affected houses and shops	No impact or negligible impact	C	No impact or negligible impact	C	No impact or negligible impact	C
Construction Cost	8.46 US$ million (1.00)	A	12.54 US$ million (1.48)	D	12.30 US$ million (1.45)	D
Evaluation	**Alternative 1 for Section A** is advantageous in terms of i) measures for ground stabilization and ii) construction cost.					

A: High comparative advantage, B: Comparative advantage, C: No comparative advantage, D: Disadvantageous

Note: Construction cost does not include contingency and consultant fee.

Source: Study Team

b) Road Alignment in Makhanga Village (Section B)

The following considerations and/or problems are identified in the Makhanga village area when the raised road is built on the exiting road alignment.

- There is a possibility that at least more than 20 houses and shops and 10 huts in the market area around the level crossing with railway could be relocated.(see Photo 8-1)
- There is a possibility that the progressing erosion along the right bank of the Ruo River could influence the S151 road in the future, especially, the section with only 30 m distance between the S151 road and the Ruo River. (see Photo 8-2)

Photo by Study Team, November 2011

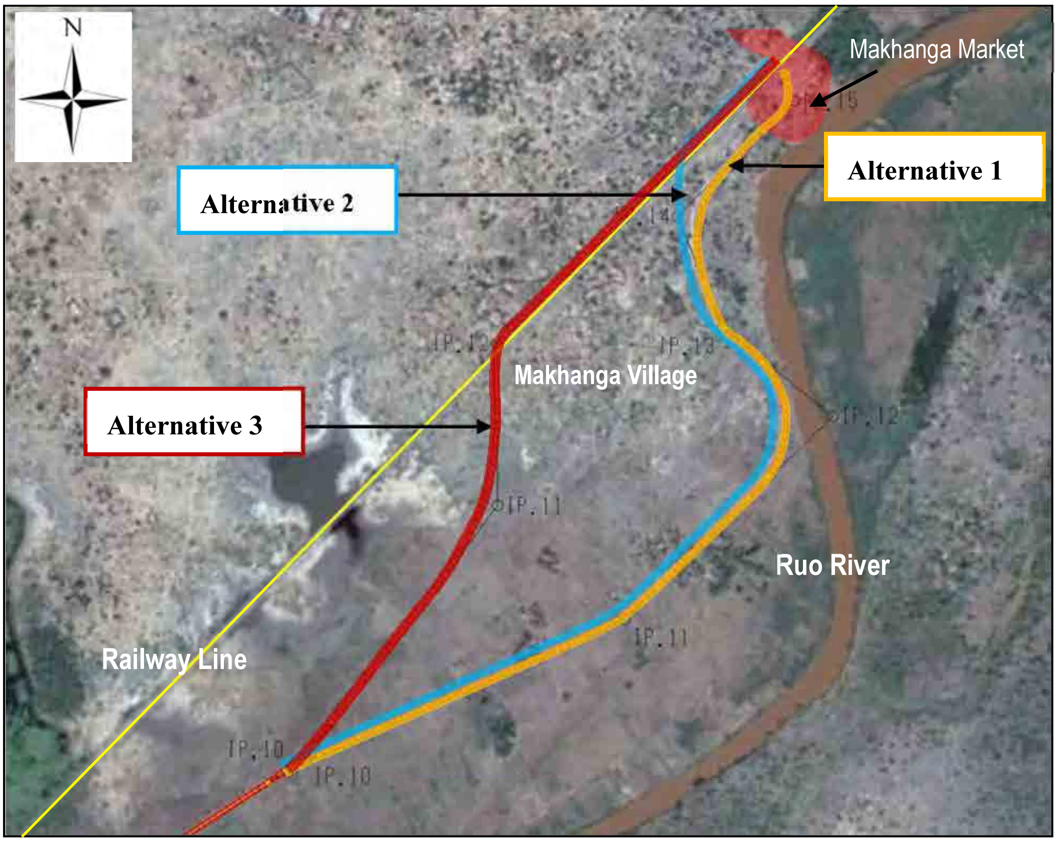
Photo 8-1 Makhanga Market Area **Photo 8-2 Bank Erosion of the Ruo River**

Thus, the Study Team conducted a comparison of the following three alternatives in Makhanga area.

Alternative 1: Existing Road Alignment
Alternative 2: Market Area Detour Alignment
Alternative 3: Railway Line Alignment

As a result of the comparison, Alternative 3 is most advantageous in terms of i) design element, ii) the Ruo River bank erosion, iii) road damage caused by flood and iv) construction cost. However, further examinations for selecting the final alignment is recommended for the following reasons. (see Figure 8-2 and Table 8-2)

- To clarify and grasp the location and number of houses, shops and public facilities along the railway in order to set the road alignment and location of level crossings across the railway, and then to obtain social consensus.
- To clarify and grasp geological conditions in detail on the planned alignment.
- To clarify and grasp the erosion mechanism of the Ruo River bank in order to justify realignment of the road.



Source: Study Team

Figure 8-2 Road Alignment Alternatives in Makhanga Village

Table 8-2 Road Alignment in Makhanga Village (Section B)

Section B: Inside Makhanga Village (L = 3 km)						
Alternative	**1** **Existing Road Alignment**		**2** **Market Area Detour Alignment**		**3** **Railway Line Alignment**	
Design Elements	R = 700, 250, 140, 300, 75	D	R = 700, 250, 140, 75	D	R = 700, 250, 75	A
Affected houses and shops	20 houses and shops and 10 huts could be affected	D	5 houses and shops could be affected	A	20 houses and shops could be affected	D
Land Acquisition	Not required (within ROW)	A	1.6 ha required	D	56.8 ha required	D
Ruo River Bank Erosion	Road embankment could be influenced due to narrow offset distance (30 m)	D	Road embankment could be influenced due to narrow offset distance (30 m)	D	Road embankment would not be influenced	A
Road damage caused by flood	Damage could be expected	D	Damage could be expected	D	Less damage could be expected	A
Flooding Impact in Makhanga Area	Road embankment could ha flood prevention functions in area between the road and railway	A	Road embankment could have partial flood prevention functions in Makhanga area	B	Keeping the status quo	C
Makhanga Railway Station	Keeping the status quo	C	Relocation of Makhanga railway station required	D	Relocation of Makhanga railway station not required	C
Construction Cost	4.07 US$ million (1.17)	D	4.10 US$ million (1.18)	D	3.48 US$ million (1.00)	A
Evaluation	**Alternative 3 for Section B** is advantageous in terms of i) design element, ii) bank erosion of Ruo River, iii) road damage caused by flood and iv) construction cost, however, the number of affected houses and shops as well as the area of land to be acquired should be investigated in detail.					

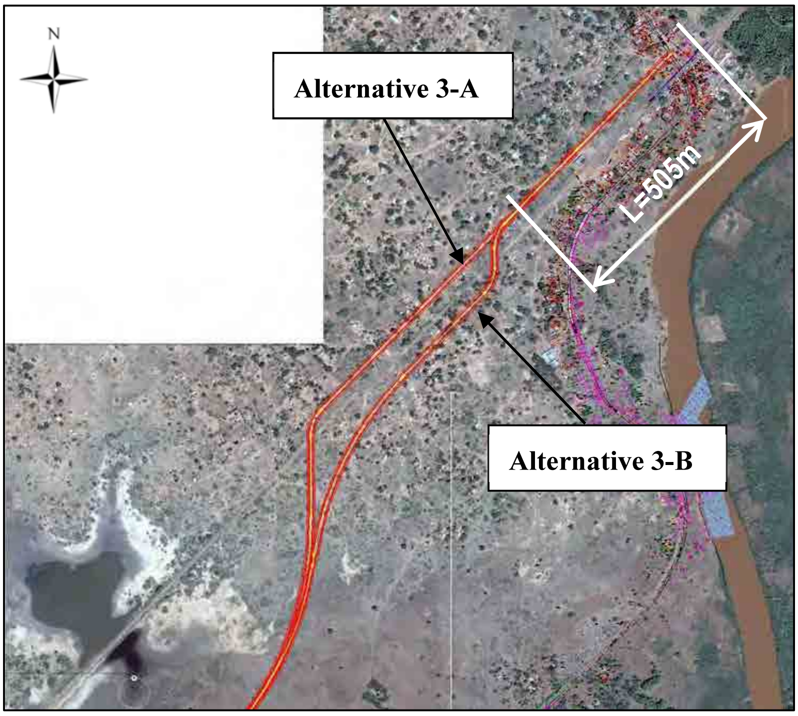
A: High comparative advantage, B: Comparative advantage, C: No comparative advantage, D: Disadvantageous

Note: Construction cost does not include contingency and consultant fee.

Source: Study Team

c) Considerations for the Section of the Railway Level Crossing in Makhanga

- A crossing angle with the railway line of more than 45° is stipulated in order to provide adequate visibility and safety to traffic.
- Comparing Alternative 3-A and 3-B, the former is advantageous in terms of road alignment the latter is used for a minimum continuous curve radius of 75 m at the level crossing point. (see Figure 8-3)
- Makhanga Railway Station is required the length along the railway of 505 m to rehabilitate and establish station facilities. If less than 505 m, the station could be relocated in the eastern direction (Sandama side).



Source: Study Team

Figure 8-3 Alignment at the Level Crossing Point

d) Considerations for the Section of the Shire River Crossing

The existing Kamuzu Truss Bridge only provides traffic services across the Shire River presently. This combined rail-road bridge only has one lane on the road due to the narrow width. Thus, in line with the upgrade plan of S151 in the Master Plan, a new road bridge with two lanes across the Shire River instead of the existing Kamuzu Truss Bridge will be constructed in order to establish a two-way paved road between Thyolo and Bangula.

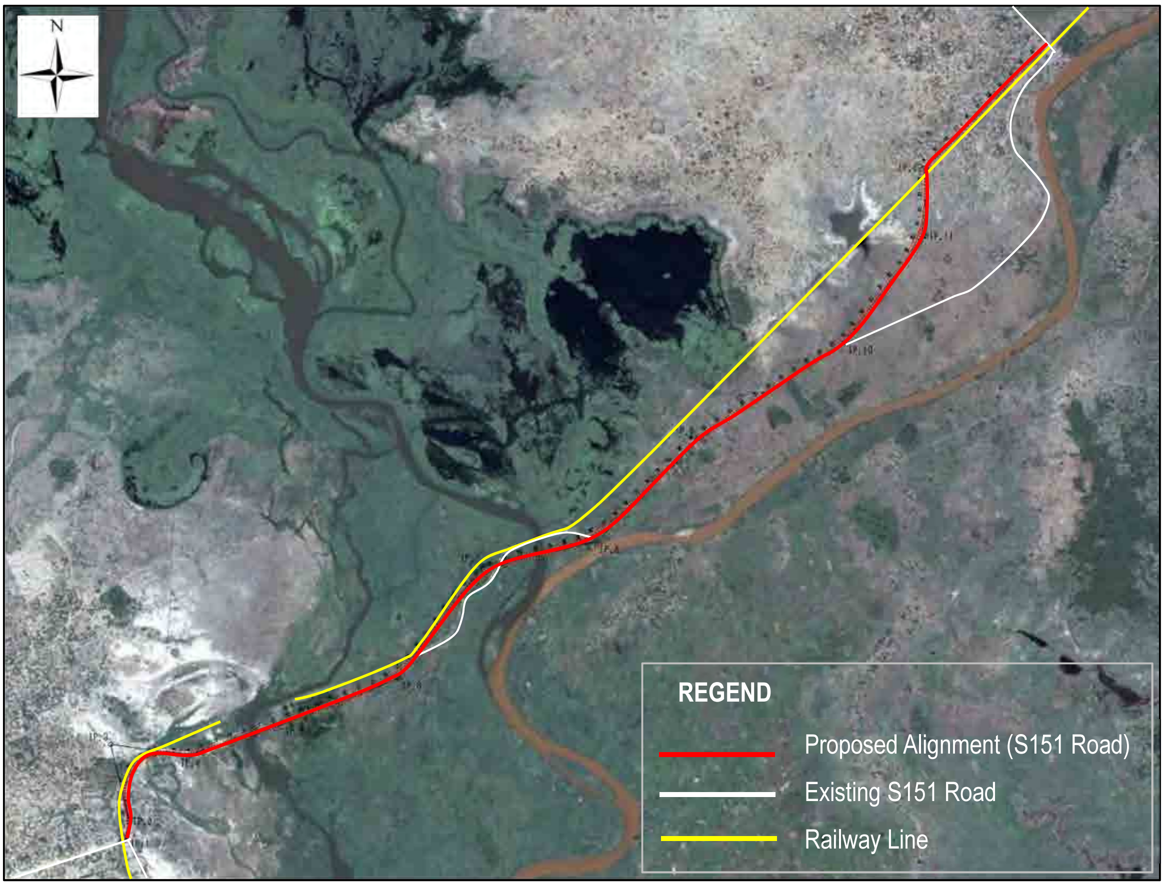
The existing alignment of approach roads to the Kamuzu Truss Bridge is composed by an 80 m radius curve. The Study Team proposes that new alignment around the New Shire Bridge be improved corresponding to the design speed of 80 km/h considering location of the planned bridge and topographical conditions. This makes a substantial improvement on the existing alignment of approach roads (curve radius of 700 m and 900 m) (see Figure 8-4).

Source: Study Team

Figure 8-4 Road Alignment around the New Shire Bridge

e) Proposed Road Alignment

Proposed road alignment is shown in Figure 8-5



Source: Study Team

Figure 8-5 Proposed Road Alignment between Makhanga and Bangula

(3) Design Speed

According to Design Report of Thyolo – Makwasa – Thekerani – Muona – Bangula Road Project (Upgrading of S151), a design speed between Thyolo and Makhanga was proposed at 60 km/h for the rolling terrain and 50 km/h for the mountain terrain. The design speed based on the existing alignment between Makhanga and Bangula is estimated at 30 km/h to 60 km/h.

The proposed design speed for the project site between Makhanga and Bangula is 80 km/h considering the plan for a new railway bridge at the Chiromo washaway section which was washed away, as well as a plan for a new road bridge around the confluence of the Shire River and the Ruo River in terms of economic efficiency.

On the other hand, the road runs through a market and/or residential area and there is a level crossing across the railway in Makhanga village. The design speed in Makhanga village area is proposed at 30 km to 60 km in order to mitigate relocation of houses and shops and securing safe traffic.

- Design Speed: 80 km/h
- Village area and section of level crossing with railway: 30 km/h to 60 km/h

(4) Road Longitudinal Plan

a) Clearance

- 0.6 m from H.W.L to the road surface of embankment section
- 1.0 m from H.W.L to the bottom of bridge girder

b) Gradients and Vertical Curves

Gradients and vertical curves of the design road are as follows. (see Table 8-3)

Table 8-3 Vertical Alignment

STA.	Cumulative Distance	Vertical Height	Gradient (%)	Vertical Length	Vertical Curve
0+00	0	49.600	-0.285714	-	-
1+40	140	49.200	0.000000	0	0
10+19	1,019	49.200	2.500000	140	5,600
12+63	1,263	55.300	-2.500000	240	4,800
14+91	1,491	49.600	0.000000	140	5,600
32+38	3,238	49.600	2.000000	140	7,000
36+23	3,623	57.300	-2.000000	200	5,000
39+38	3,938	51.000	0.000000	140	7,000
57+70	5,770	51.000	0.176101	0	0
73+60	7,360	53.800	0.009021	0	0
84+68.5	8,468.5	53.900	-	-	-

Source: Study Team

(5) Cross Section Elements

The total road width is 9.7 m since the design road is categorized as a primary road network. The width of the carriageway is 6.7 m and the hard-shoulder for both sides is 1.5 m. The cross-slope of the carriageway and hard-shoulder is 2.5%.

- Road Type: Primary Road (Secondary Road)
- Total Road Width: 9.7 m

- Carriageway: 6.7 m, shoulder: 1.5 m (Left and right)
- Carriageway and shoulder cross slope: 2.5%

(6) Future Traffic Volume

Daily traffic volume in 2030 on S151 between Makhanga and Bangula, which is the targeted project area, is 1,606 vehicles per day based on traffic demand forecast analysis. Traffic volume by type of vehicle are summarised as follows. (see Table 8-4)

Table 8-4 Future Traffic Volume in 2030

Route	Section		Traffic Volume (vehicle/day)					
	From	To	Total	Passenger Cars	Minibus	Buses	Small Trucks	Large Trucks
S151	Seven	Thyolo	208	137	44	3	21	3
	Makhanga	Seven	1,395	927	381	24	54	9
	Bangula	Makhanga	1,606	1,076	467	30	28	5

Source: Study Team

(7) Pavement Design

a) Design Process

- Estimating the cumulative traffic load expected during the design life
- Defining the strength of subgrade over which the road will be built
- Defining the normal operating climate (wet or dry)
- Determining any practical aspects which influence the design selection
- Selecting possible pavement structure

b) Design Life

According to Southern Africa Transport and Communications Commission (SATCC) code of practice for the design of road pavements, design life is in the range of 10 to 20 years depending on the situation. This time, the design life is proposed at 15 years considering data reliability and the importance of service.

c) Design Traffic Class

The one-directional cumulative traffic flow for each category expected over the design life is forecasted using the following formula.

$$DT = T \times 365 \times \frac{(1 + r/100)^{p} - 1}{r/100}$$

where

DT is the cumulative design traffic in a vehicle category, for one direction

T = average daily traffic in a vehicle category in the first year (one direction)

r = average assumed growth rate, percent per annum

p = design life in years

The following formula is used for converting real axle loads to Equivalent Standard Axles (ESAs).

$F = (P/8160)^{n}$ (for loads in kg) or $F = (P/80)^{n}$ (for loads in kN)

where

F is the load equivalency factor in ESAs

P = axle load (in kg or kN)

n = relative damage exponent

ESAs for S151 between Makhanga and Bangula are calculated at 0.43 E+06. (see Table 12-5) Traffic range (million ESAs) is 0.3 < 0.43 <0.7, thus, design traffic classes are categorized in T2.

Table 8-5 Design ESAs Value

Vehicle Type	Cumulative design traffic DT	Factor in ESAs $(P/8160)^n$	ESAs DT * $(P/8160)^n$
Passenger cars	1,951,469	0.01	19,515
Minibus	847,021	0.01	8,470
Buses/Small Trucks	107,954	2.539	274,095
Large Trucks	8,304	15.922	132,216
Total			434,296 0.43 E+06

Note: r = 5.7%, n=4

Source: Study Team

d) Subgrade Classification

Subgrade classification is categorized in S2 because the design California Bearing Ratio (CBR) could be assumed at 4% which refers to a CBR-value for subgrade of the existing road. Although there is no data for filling material at the expected quarries in order to evaluate subgrade classification, CBR-values of 6% at borehole 4 (BH-4) and 14% at BH-8 are obtained from the existing road.

e) Operating Climate

Annual average precipitation at Makhanga between 2005 and 2009 was 739 mm > 500 mm. Thus, the project site is categorized as a Wet Region for design purposes.

f) Proposed Pavement Layer

- Surface: Double Surface Dressing (DBST)
- Granular Base: 150 mm (Soaked CBR > 80%)
- Granular Subbase: 200 mm (Soaked CBR > 30%)
- Selected layer: 200 mm (Soaked CBR > 15%)

(8) Road Drainage

Almost all the existing drainage consists of 600mm diameter pipe culverts, and at some cross points there are 1500 or 2000mm diameter pipe culverts. Drainage structures are proposed along the design road in consideration of the flooding that the area is prone to and for efficient maintenance purposes (see Table 8-6).

- To replace the existing 600mm diameter pipe culvert with 900 mm diameter culverts.
- To place additional pipe culverts at 450 m to 500 m intervals, this is average for the primary road network in the South.

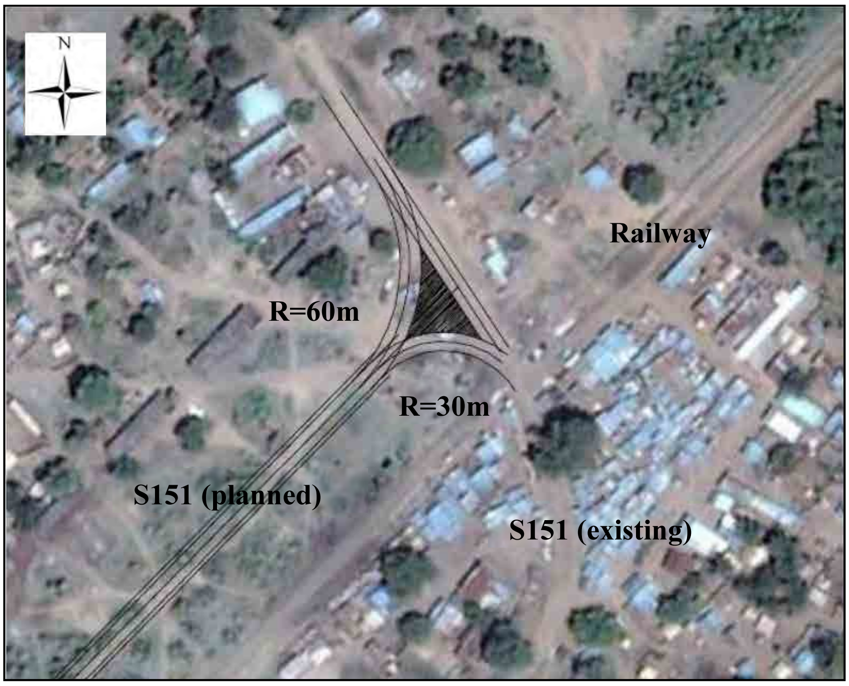
Table 8-6 Drainage Construction Plan

Location Km	Drainage				Remarks
	Design		Existing		
0.00 (Bangula)		(D x no.)		(D x no.)	
0.43	PIPE	900 x 1	PIPE	600 x 1	
0.60	PIPE	900 x 1	PIPE	600 x 1	
0.64	-	-	PIPE	2000 x 6	No functioning
1.27	BRIDGE	-	PIPE	5000 x 3	Chiromo Road Bridge
1.79	PIPE	900 x 1	PIPE	600 x 1	
2.71	PIPE	900 x 1	PIPE	600 x 1	
3.15	PIPE	900 x 1	-	-	additional
3.60	BRIDGE	-	BRIDGE		Kamuzu Truss Bridge
3.96	PIPE	1500 x 2	PIPE	1500 x 2	
4.22	PIPE	900 x 1	-	-	additional
4.60	PIPE	900 x 1	-	-	additional
5.00	PIPE	900 x 1	-	-	additional
5.36	PIPE	900 x 2	PIPE	600 x 2	
5.72	PIPE	900 x 1	PIPE	600 x 1	
5.80	PIPE	900 x 1	PIPE	600 x 1	
6.00	PIPE	900 x 1	-	-	additional
6.50	PIPE	900 x 1	-	-	additional
7.00	PIPE	900 x 1	-	-	additional
7.30	PIPE	900 x 1	-	-	additional

Source: Study Team

(9) Intersection

A T-junction is proposed at the end point of the design road for coordination with the S151 upgrade project between Thyolo and Makhanga. (see Figure 8-6)



Source: Study Team

Figure 8-6 Intersection in Makhanga Area at the End Point

(10) Road Safety

a) Installation of Safety Facilities

The embankment height of the approach roads to the Chiromo Road Bridge and the New Shire Bridge is approximately 5.5 m and 7 m from the ground level, respectively. Thus, it is proposed to install guardrails along both sides of the approach roads of approximately 180 m for the Chiromo Road Bridge and 300 m for the New Shire Bridge. The guardrails are to be located on the outside of the 1.5 m shoulders at a recommended marginal width of 1.0 m.

b) Road Signs and Pavement Markings

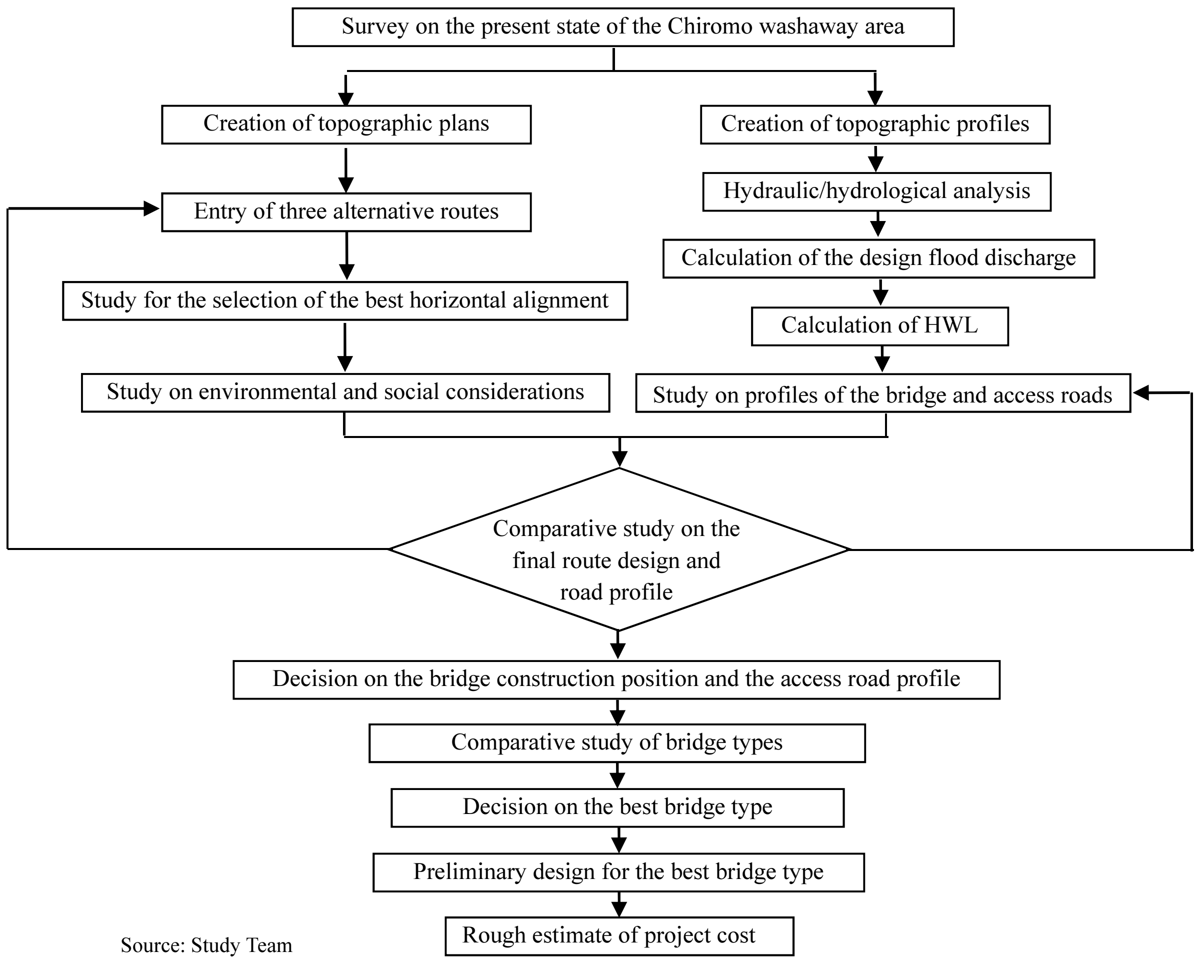
The following road signs and pavement markings are to be set in appropriate positions:

- Regulatory signs such as speed limits
- Information signs such as to indicate destinations at a proper location
- Danger signs such as at an approach of an intersection, sharp curves and railway level crossings
- Pavement markings such as centreline and road strips

8.2.2 Preliminary Design of Chiromo Road Bridge

(1) Workflow of the Preliminary Design

In the preliminary design, studies required for the construction of a road bridge in the Chiromo washaway area, including a survey on the present state of the area and studies for the selection of a bridge construction position, road alignment, scale of the bridge and bridge type, were implemented. The results of these studies were used for the selection of the best bridge type. Figure 8-7 shows the workflow of the preliminary design.



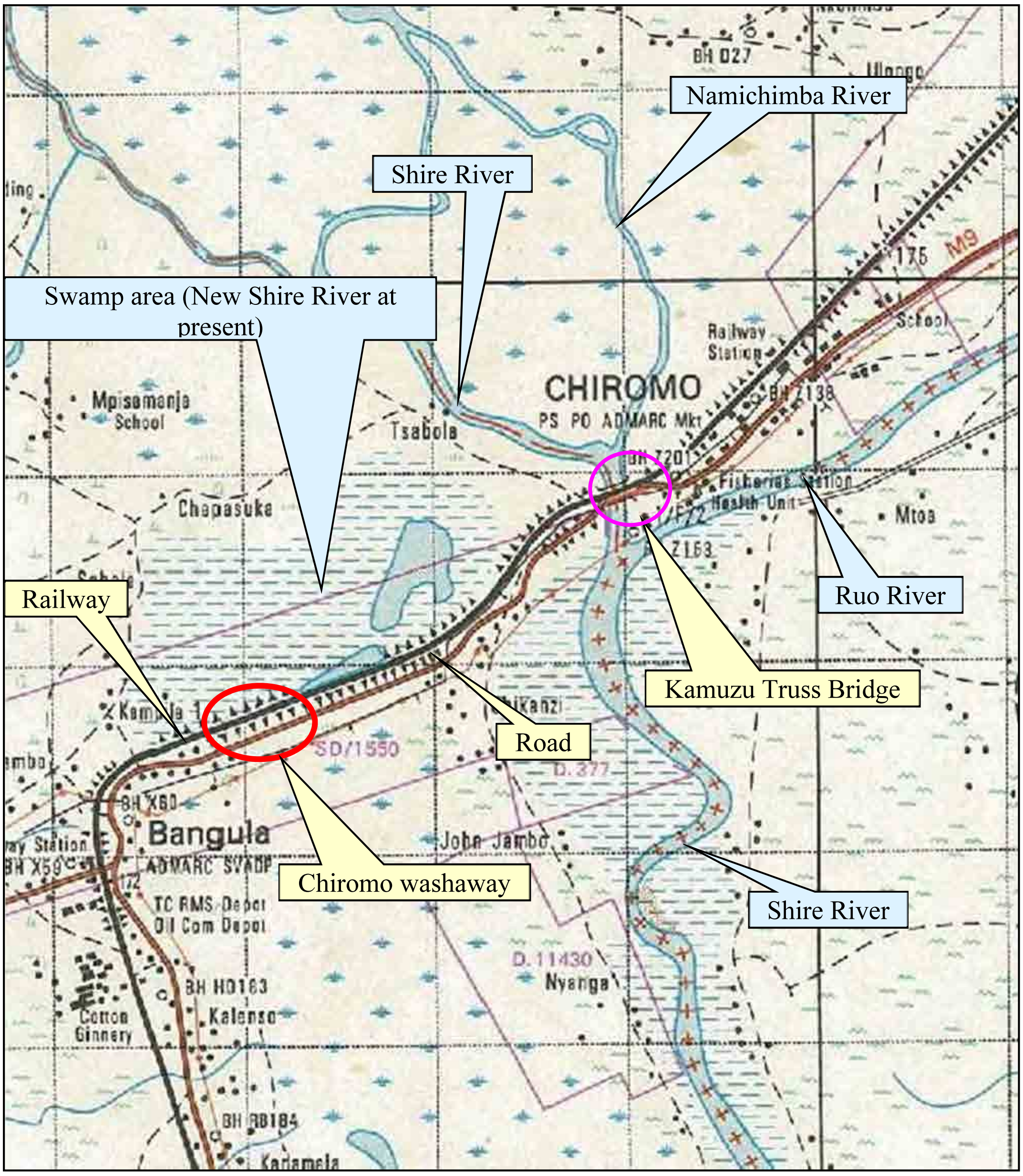
Source: Study Team

Figure 8-7 Workflow of the Preliminary Design

(2) Present State of the Planned Bridge Construction Position

a) Old Map of the Area between Chiromo and Bangula

The old map of the area between Chiromo and Bangula is shown in Figure 8-8. Since this map was created more than 20 years ago in 1989, the current topography of the area, especially that of the swamp, is significantly different from that on the map. The most significant topographic change is that the swamp between Chiromo and Bangula is found on the north of the railway embankment. The cause of this change is from the large-scale flood in 1997, in which the river bank upstream of the Shire River collapsed and a large amount of flood water spilt over into the swamp, which washed away the railway embankment and eventually created a branch stream of the Shire River through the swamp.



Source: Study Team

Figure 8-8 Old Map of the Area between Bangula and Chiromo

b) Present Status of the Chiromo Washaway

Figure 8-9 shows the results of the survey on the present state of the Chiromo washaway area where the railway and the road are disrupted as a large number of the railway and road embankments were washed away in the large-scale flood in 1997. While the length of the railway embankment washed away was approximately 360 m, only about 100 m of road embankment was washed away was approximately 100m, of about a quarter of the length of the washed-away railway embankment. Since the railway embankment had been constructed on the north side of the road embankment, the railway embankment worked as a river bank and protected the road embankment from the flood water to some extent during the flood. This is thought to be why the damage caused by the flood water on the road embankment was smaller than that on the railway embankment.

(3) Study on the Bridge Construction Position and Access Roads

The best bridge construction position shall be selected among the three alternatives mentioned below using the results of a comparative study on the bridge construction positions and access roads of the three alternatives. In the comparison, the three alternatives shall be analysed comprehensively, with bridge length, cost efficiency, alignment of the access roads, impact on the access roads to the New Shire River, flood control measures, land acquisition, construction efficiency and impact on the natural and social environments taken into full consideration, and the best alternative shall be identified from the results of the analysis.

a) Alternative 1 (Use the existing road)

While more than 360 m of the railway embankment on the Bangula side was washed away, the length of the washed away road embankment was less than 100m. Alternative 1 is to make the most of the remaining road embankment on the Bangula side. Since the bridge in this alternative is significantly affected by the New Shire River when it floods, a survey shall be implemented to study and confirm the condition of the river.

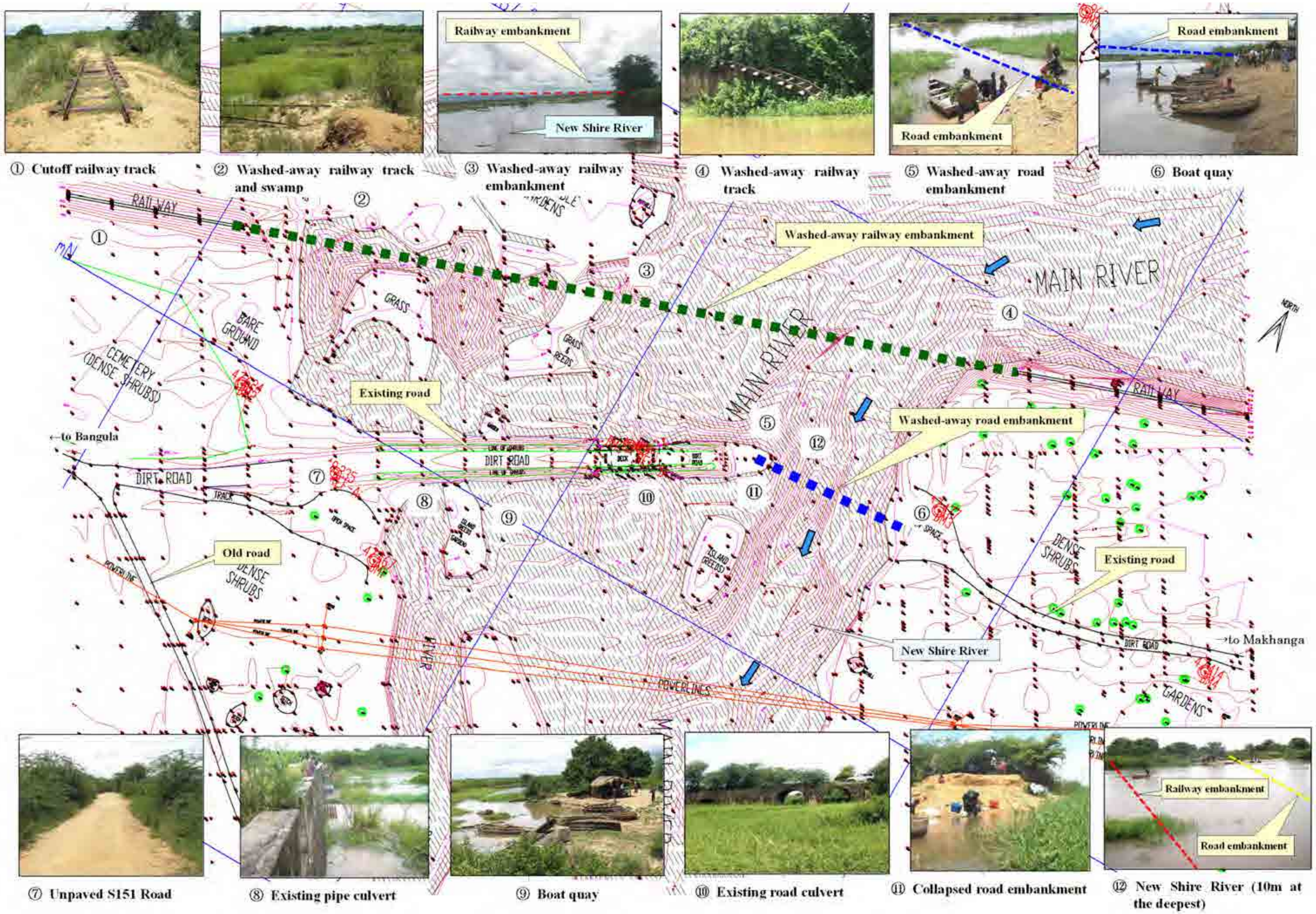
b) Alternative 2 (The best alignment)

Since Alternative 1 makes the most of the existing road, there shall be an S-shaped section on the access road on the Makhanga side of the new bridge. This is an alternative to connect the Bangula side and the Makhanga side of the existing road with a straight route without an S-shaped section.

c) Alternative 3 (Use the old road as a detour route)

This is an alternative to construct a new road which makes a large detour to the south of the Chiromo washaway area using the old road on the Bangula side in order to minimize the effect of the New Shire River on the bridge. Since this alternative will require a large area of land to be acquired, sufficient environmental and social considerations will have to be taken in the project design.

Table 8-7 shows a comparison of the three alternatives above based on the results of the field reconnaissance and topographical surveys.



Source: Study Team

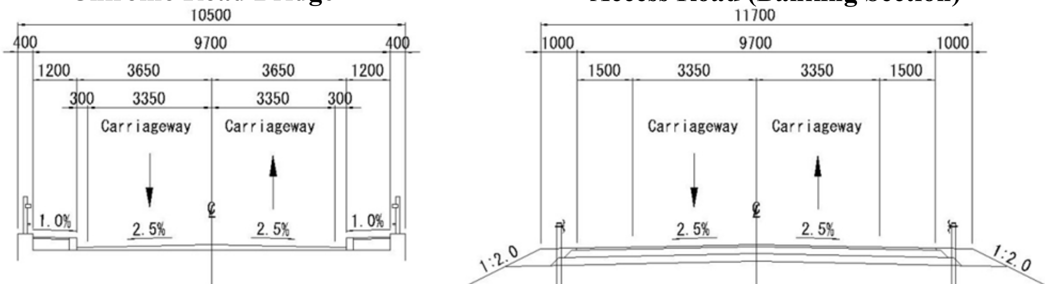
Figure 8-9 Results of the Survey on the Chiromo Washeaway Area

(4) Comparative Study of Bridge Types

a) First-Phase Comparative Study of Bridge Types

Three bridge types are compared for selecting a structure of the bridge to be constructed at the best position selected in (3) above. A concrete bridge is the first choice because of versatility and low cost of the material. However, a steel bridge is also considered as a candidate bridge type depending on the span lengths. The decision on the scale of the bridge, its length and span length is made based on the analysis of the results of the hydrological survey, and appropriate specifications for the width of the bridge shall be established by referring to the results of a traffic survey conducted in the Study and the road design standards of Malawi. The width of the bridge and the approach road are shown in the following figures (see Figure 8-10).

Chiromo Road Bridge **Access Road (Banking Section)**



Source: Study Team

Figure 8-10 Width of Bridge and Approach Road

The following three alternative bridge types shall be compared:

- **Alternative 1:** PC 8-span connected post-tensioned T-girder bridge
- **Alternative 2:** PC 3-span continuous box-girder bridge
- **Alternative 3:** Steel 3-span continuous truss bridge

Table 8-8 shows the results of the comparative study of the three alternatives above.

b) Second-Phase Comparative Study of Bridge Types

Alternative 2 (PC 3-span continuous box-girder bridge) was selected as the most preferable bridge type in the 1) First-Phase Comparative Study of Bridge Types above. However, this type of structure would require significantly high (8m) girders. Such girders would require a raised road profile, resulting in very high abutments. The heights of the abutments A1 and A2 are 15m and 17.5m, respectively, for the bridge in Alternative 2.

In order to reduce the abutment heights, a study on a bridge type which would reduce girder height will be needed. Since an Extradosed bridge meets such requirements, the following two alternatives shall be studied comparatively in the Second-Phase Comparative Study of Bridge Types:

- **Alternative 1**: PC 3-span continuous box-girder bridge
- **Alternative 2:** Extradosed bridge

Table 8-9 shows the results of the comparative study of the above-mentioned two alternatives.

(5) Preliminary Design

A preliminary design shall be conducted on an Extradosed bridge, which had been selected as the more preferable bridge type in the b) Second-Phase Comparative Study of Bridge Types above. In addition, when the detailed hydraulic analysis is carried out at the time of the feasibility study and if the HWL falls as a result, a PC 3-span continuous box-girder bridge may be selected instead of an Extradosed bridge.

a) Design Standards

1) Bridge Design Standards

In bridge design, the design standards of Malawi and the standard specifications established by the Southern African Transport and Communications Committee (SATCC Standard Specifications) shall be followed for specifications of strengths if locally available materials are to be used for the bridge construction. The specifications for live load and design methods in the Japanese specifications (Specifications for Highway Bridges) shall be used in the bridge design. In other words, the following design standards/specifications shall be used in the bridge design:

- Bridge Design Manual 1988 (Ministry of Works and Supplies)
- Code of Practice for the Design of Road Bridges and Culverts 1998 (SATCC)
- Specifications for Highway Bridges 2002 (JAPAN)

2) Road Design Standards

The standards established in Malawi (the Malawian standards) and the standard specifications established by the SATCC shall be followed in the road design. If neither of them provides standards/specifications for a specific item, Japanese standards (Road Structure Ordinance) shall be followed. In other words, the following design standards/specifications shall be used in the road design:

- Highway Design Manual 1978 (Ministry of Works and Supplies)
- Code of Practice for the Geometric Design of Trunk Roads 1998 (SATCC)
- Road Structure Ordinance (JAPAN)

b) Design Conditions

1) Design Live Load

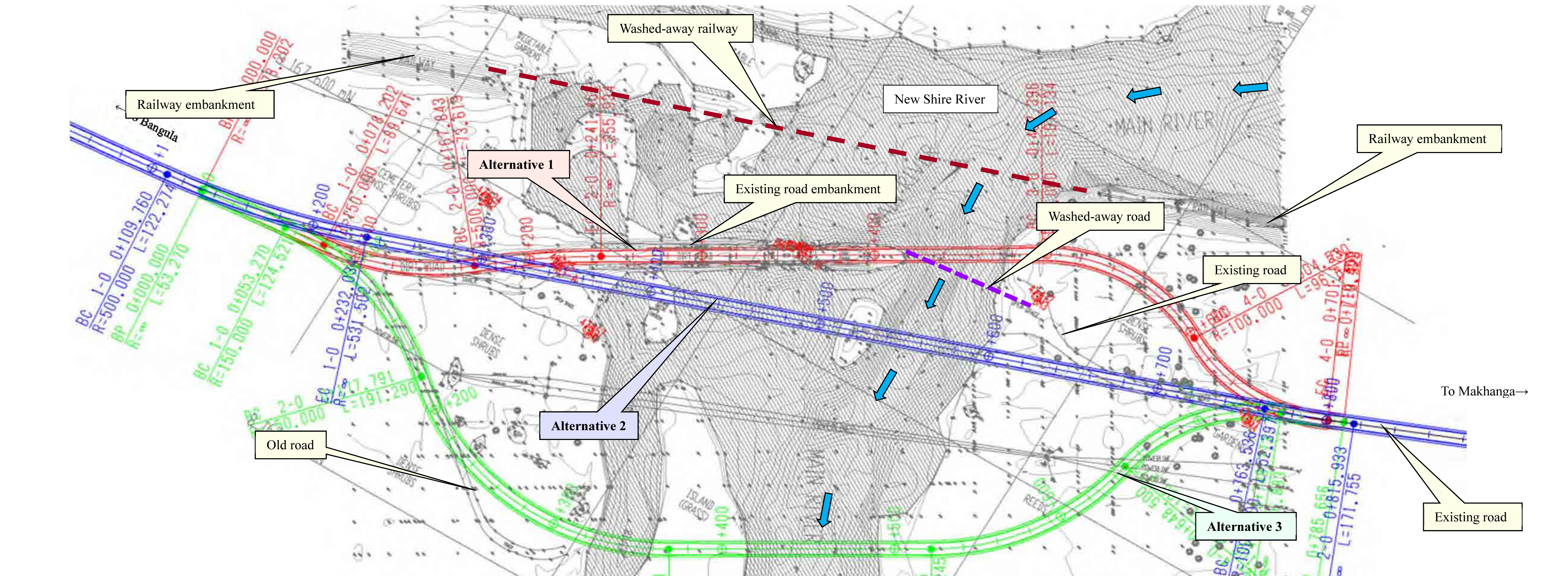
The British Standards (BS5400) referred to by the Bridge Design Manual of Malawi provide HA and HB loading as specifications for design live load on a road bridge, while the Specifications for Highway Bridges of Japan provides live load B for the design live load. Although only a little difference was found among the three, live load B of the Japanese specifications was found to be slightly safer than the other two. Therefore, live load B of the Japanese specifications shall be used as the design live load in the preliminary design.

2) Hydraulic Conditions

i) Return Period

The return period of a flood in 50 years (probability of 2%/year) is to be adopted for the preliminary design, with scales of the bridge design in the past in Africa and durable periods of bridges taken into consideration.

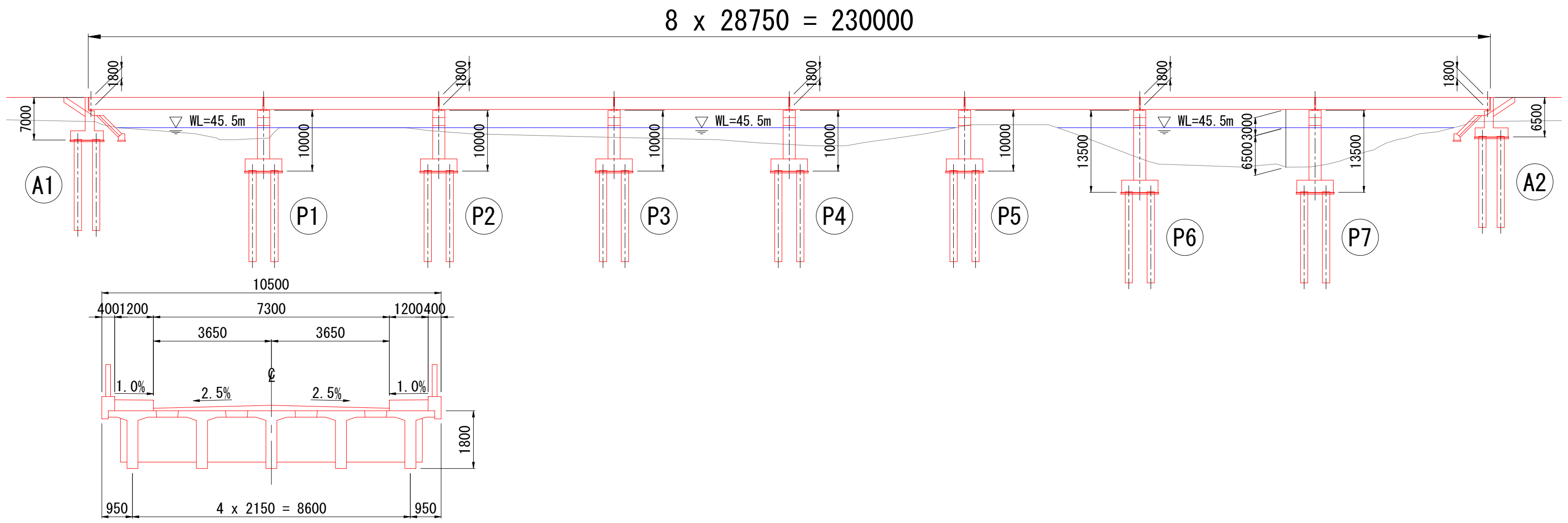
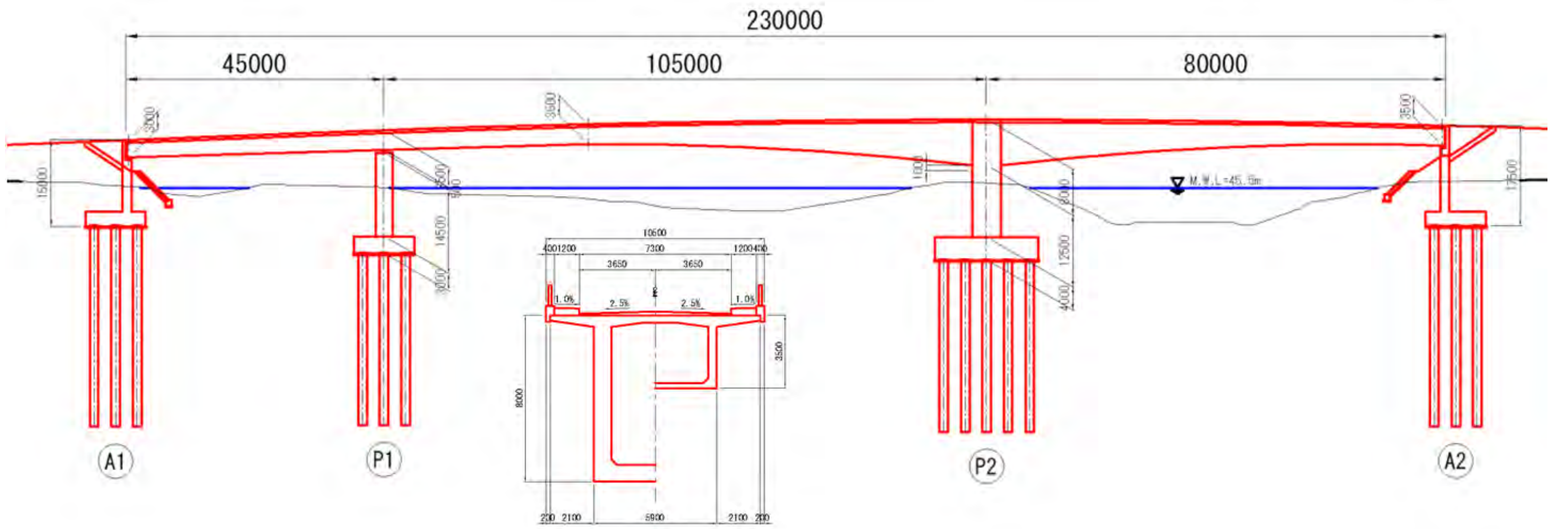
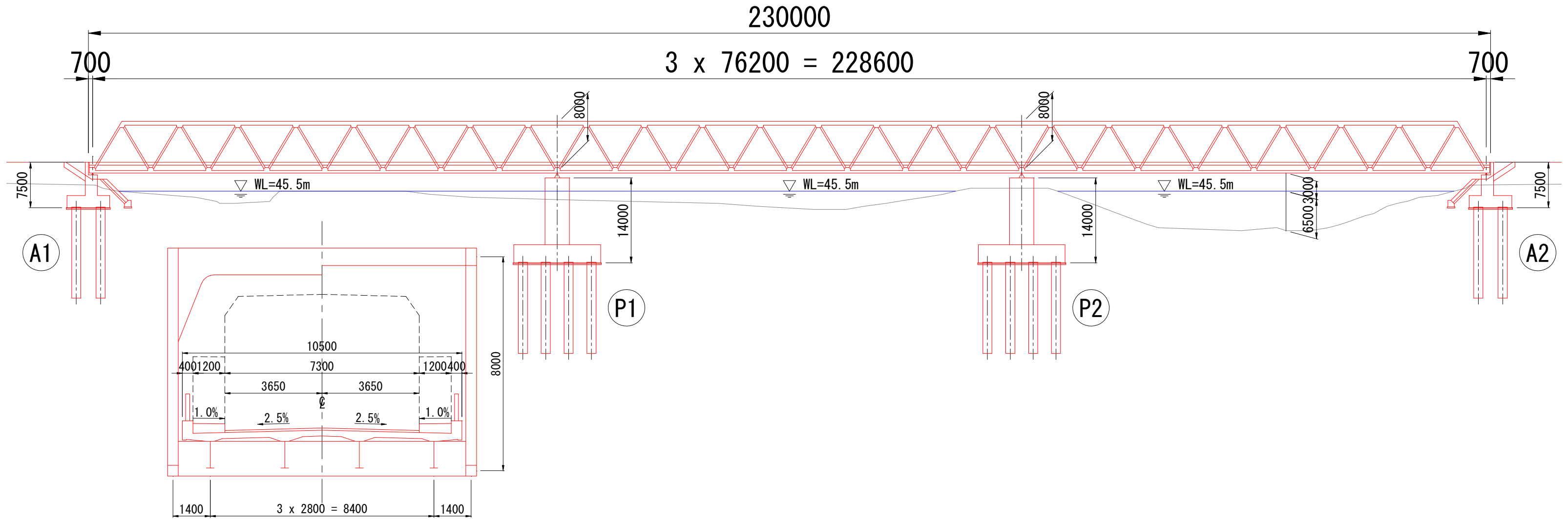
Table 8-7 Comparison of Bridge Construction Position Alternatives



Alternative		Alternative 1 (utilizing the existing road embankment)	Alternative 2 (Best alignment)	Alternative 3 (Detour using an old road)
Overview of alternative		・This is a plan to utilize the existing road embankment to the maximum.	・The existing roads on Makhanga and Bangula sides will be connected with a straight alignment.	・A big detour on the southern side will be made using an old road on the Bangula side.
Evaluation of alternative	Alignment of access road	・The alignment is unsuitable because of an S-curve in the approach to the existing road on the Makhanga side.	・Since the new access road is nearly straight, the alignment is the best of the three alternatives.	・It is the worst alignment because of two S-curves in the approach to the existing road.
	Characteristics of new bridge	・A curve in the side span is a problem in the structure.	・Being a straight bridge, there is no particular problem.	・Being a straight bridge, there is no particular problem, but the bridge length is the longest.
	Impact of the New Shire River on the access road	・The existing road is formed like a jetty so there is a direct impact from any flooding of the New Shire River.	・Since there are an existing road embankment on the Bangula side and a railway embankment on the Makhanga side, there will hardly be any impact if the New Shire River floods.	・Same as left.
	Flood control measure	・A large-scale bank protection facility must be installed in the existing road embankment.	・Since the new access road is protected by the existing road, a small-scale bank protection facility shall be sufficient.	・Same as left.
	Environmental and social considerations	・Problems such as resettlement and building removal will not occur as there is no building in this area.	・Same as left.	・Same as left.
		・Land must be acquired for the approach to the existing road on the Makhanga side.	・Land acquisition is needed for the approach to the existing road both on the Makhanga and Bangula sides.	・Land must be acquired for the approach to the existing road both on the Makhanga and Bangula sides, and the expropriation area is the largest.
	Target work (Ratio of costs)	・Bridgework, approach road work for 510 m, bank protection work (1.06).	・Bridgework, approach road work for 450 m, bank protection work (1.00).	・Bridgework, approach road work for 540 m, bank protection work (1.11).
	Overall evaluation	・The alignment is unsuitable because of an S-curve. ・There is a significant impact from any flood of the New Shire river. ・The construction cost is higher than Alternative 2 because of large-scale bank protection work.	・The alignment is the best because the new road is almost straight. ・There is little impact if the New Shire River floods. ・The construction cost is the lowest because of a small-scale bank protection work.	・The alignment is the worst because of two S-curves. ・There is little impact from any flood of the New Shire River. ・The construction cost is the highest because of the high costs of the bridge and the access road.

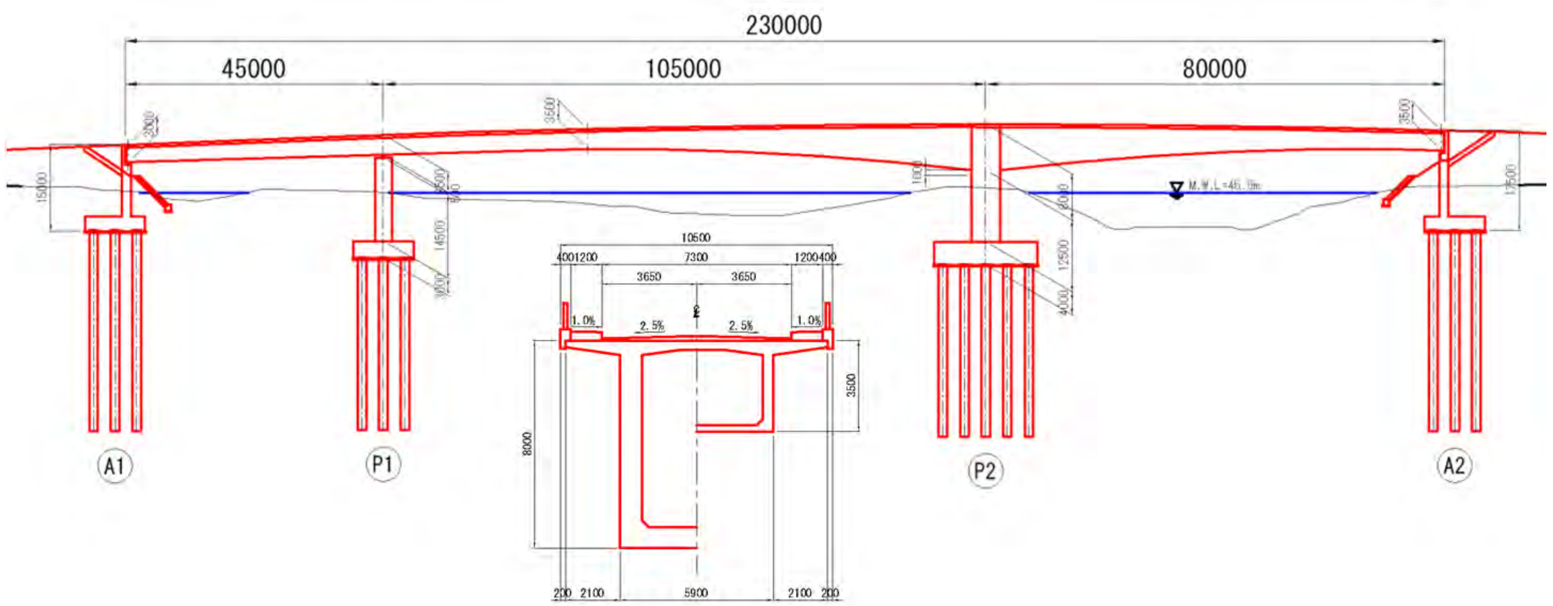
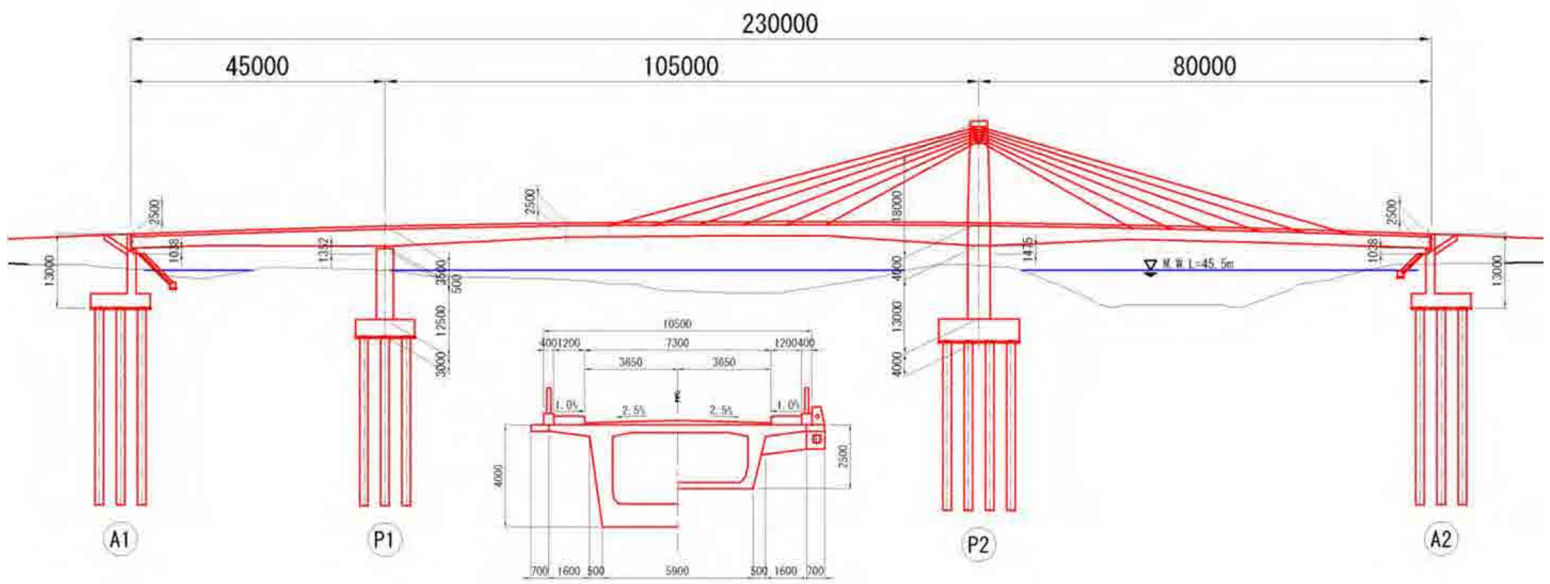
Source: Study Team

Table 8-8 The First-Phase Comparison of Bridge Types

Bridge type		Characteristics
Alternative 1: PC 8-span connected post-tensioned T-girder bridge 	Structural features	・The structure is common for a PC girder type bridge and is adopted in many past constructions. ・The connected type offers smooth driving performance and earthquake resistance.
	Construction efficiency	・Since the New Shire River is five to nine meters deep, it is extremely hard to construct bridge piers in the river. ・The adoption of an erection girder enables the construction of a superstructure without influence from the river.
	Maintenance performance	・Since it is made of concrete, the bridge itself does not require maintenance. ・Maintenance is required for bridge accessories such as bearings and expansion joints.
	River characteristics	・Having bridge piers in the river, the bridge has the highest impact on the river. ・The reduction of river cross-section exceeds 6% (standard value: 5%).
	Cost efficiency	・The cost of this bridge type becomes somewhat higher than the alternative 2. (Construction cost ratio: 1.01).
	Overall evaluation	・The construction of bridge piers in the river is extremely hard due to the depth. ・Despite high cost efficiency and maintenance performance, this bridge type had better not be adopted due to the reduction of river cross-section exceeding the standard value. △
Alternative 2: PC 3-span continuous box-girder bridge 	Structural features	・A PC box-girder bridge type is appropriate for long spans and was adopted in many past constructions. ・The continuous structure offers smooth driving performance and earthquake resistance.
	Construction efficiency	・The construction of bridge piers is easy since they are constructed on islands. ・The adoption of the Dywidag method enables the construction of the superstructure without influence from the river.
	Maintenance performance	・Since this is a concrete bridge, basically no maintenance is needed. ・Maintenance is required for bridge accessories such as bearings and expansion joints.
	River characteristics	・Having bridge piers on the island, the bridge has no impact on the river. ・The reduction of river cross-section is less than the standard value of 5%.
	Cost efficiency	・This bridge type is the most economic. (Construction cost ratio: 1.00)
	Overall evaluation	・The cost efficiency of this bridge type is the highest. ・The reduction of river cross-section is below the standard value. ・This bridge type is the most desirable alternative in overall evaluation because of cost efficiency, construction efficiency, and river characteristics. ○
Alternative 3: Steel 3-span continuous truss bridge 	Structural features	・A truss bridge is appropriate for long spans and adopted when the adoption of a PC bridge is difficult. ・The continuous structure offers smooth driving performance and earthquake resistance.
	Construction efficiency	・The adoption of the cantilever erection method enables construction of the bridge without influence from the river. ・The on-site assembly of truss members makes the construction period the shortest.
	Maintenance performance	・Being a steel bridge, there is a problem of corrosion and recoating is needed. ・Maintenance is required for bridge accessories such as bearings and expansion joints.
	River characteristics	・Having piers in the river, the bridge has an impact on the river. ・The reduction of river cross-section is below the standard value of 5%.
	Cost efficiency	・Being a steel bridge, both the construction and maintenance costs are high, and the cost efficiency is the lowest. (Construction cost ratio: 1.16)
	Overall evaluation	・Being a steel bridge, the maintenance cost is the highest. ・Although this bridge type is appropriate for long spans, the cost efficiency is the lowest because it is a steel bridge. ×

Source: Study Team

Table 8-9 The Second-Phase Comparison of Bridge Types

Bridge type		Characteristics
Alternative 1: PC 3-span continuous box-girder bridge 	Structural features	The continuous structure offers smooth driving performance, earthquake resistance, and maintenance performance.
	Girder height	・With the maximum span length of 105 m, the girder height is as high as 8.0 m.
	Abutment height	・The high girders make the A1 and A2 abutments as high as 15 m and 17.5 m, respectively.
	Embankment height	・The high abutments make the embankments of the A1 and A2 abutments as high as 8.1 m and 9.7 m, respectively.
	Cost efficiency	・Although the cost for the superstructure is lower than in Alternative 2, the cost for the substructure is considerably high. The overall construction cost is higher than that of Alternative 2. ・Ratio of overall construction cost: 1.24
	Overall evaluation	・The high girders make the abutments and embankments very high. ・Although the cost for the superstructure is lower than in Alternative 2, the cost for the substructure is considerably high. The overall construction cost is higher than that of Alternative 2. This alternative has an inferior cost efficiency compared to Alternative 2. △
Alternative 2: Extradosed bridge 	Structural features	・The Extradosed type, more appropriate for long spans than Alternative 1 (PC box-girder type), is often used for the span lengths of 100 m to 200 m and was adopted in many past constructions. ・The continuous structure offers smooth driving performance, earthquake resistance, and maintenance performance.
	Girder height	・Since the girder height can be kept low with this bridge type, the maximum girder height of this bridge is 4 m, half the girder height of Alternative 1.
	Abutment height	・The low girders make both the A1 and A2 abutments 13 m high, considerably lower than those in Alternative 1.
	Embankment height	・The low abutments make the embankments of the A1 and A2 abutments as low as 6.1 m and 5.3 m, respectively, considerably lower than those in Alternative 1.
	Cost efficiency	・Although the cost for the superstructure is higher than that of Alternative 1, the cost for the substructure is considerably low. The overall construction cost is lower than that of Alternative 1. ・Ratio of overall construction cost: 1.00
	Overall evaluation	・The low girders make the abutments and embankments quite low. ・Although the cost for the superstructure is higher than that of Alternative 1, the cost for the substructure is considerably low. The overall construction cost is low. This alternative has a superior cost efficiency compared to Alternative 1. ○

Source: Study Team

ii) Design Flood Discharge

The design flood discharge of the return period of 50 years of 1,200m^3/s was deduced from the results of the hydraulic/hydrological analysis.

iii) Design High Water Level (HWL)

The design HWL of 48.4 m was deduced from the results of the hydraulic/hydrological analysis and the design flood discharge.

iv) Scour Depth

The upper surface of the footing of the piers should be positioned at least 2m below the deepest riverbed of the New Shire River with the possibility of scour taken into consideration. The bottom surface of the footing of the abutments should be positioned below the deepest riverbed.

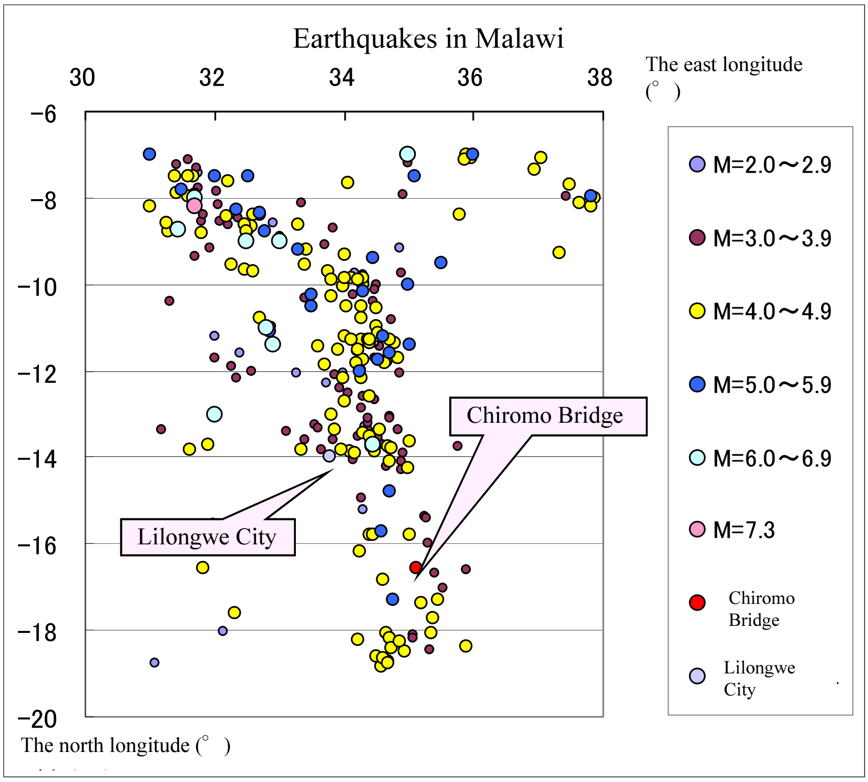
v) Revetment

Wet masonry revetments are to be built around the abutments to protect them from possible scour.

3) Seismic Load

i) Occurrence of Earthquakes in Malawi

Figure 8-11 shows the distribution of epicenters of earthquakes that occurred in Malawi during the period between 1901 and 2007.

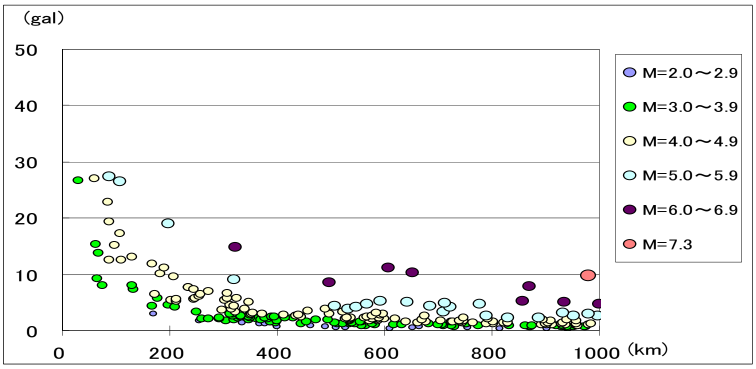


Source: Study Team

Figure 8-11 Distribution of Epicenters of Earthquakes that Occurred in Malawi

ii) Seismic Acceleration at the Chiromo Road Bridge

Figure 8-12 shows the distribution of seismic acceleration caused by earthquakes that occurred in Malawi observed at the Chiromo Road Bridge.

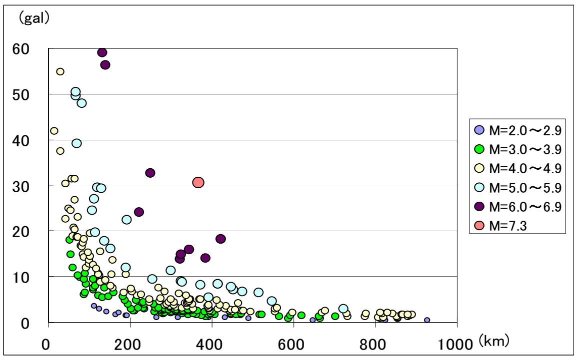


Source: Study Team

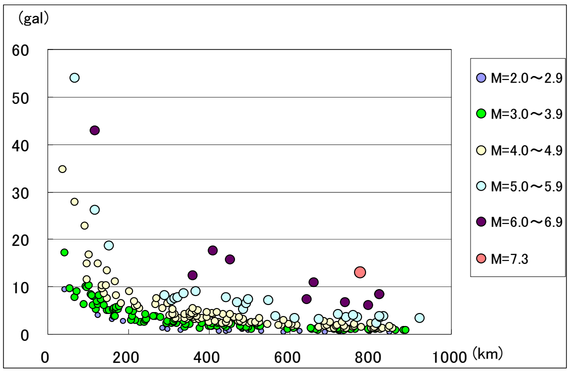
Figure 8-12 Distribution of Seismic Acceleration at the Chiromo Road Bridge

iii) Seismic Acceleration Observed at Bridges Constructed with Japan's Grant Aid

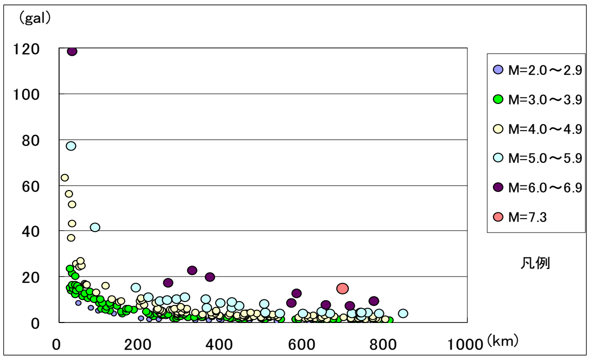
Figure 8-13 show the distributions of seismic acceleration observed at "South Rukuru Bridge", "Mangochi Bridge", "Luwazi Bridge" and "Nankokwe Bridge", respectively, all of which had been constructed with Japan's Grant Aid.



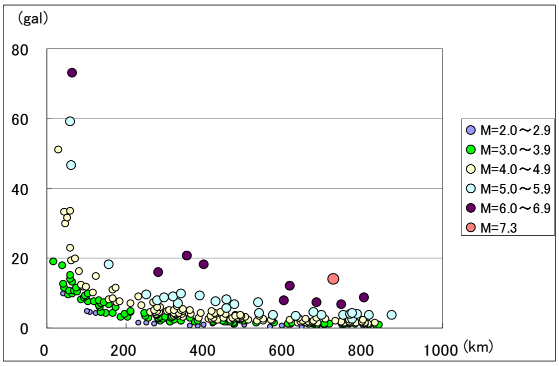
South Rukuru Bridge



Mangochi Bridge



Luwazi Bridge



Nankokwe Bridge

Source: Study Team

Figure 8-13 Distribution of Seismic Acceleration at Bridges Constructed by Japanese ODA

iv) Design Horizontal Seismic Scale at the Chiromo Road Bridge

A design horizontal seismic coefficient (Kh) of 0.10 is considered appropriate for the Chiromo Road Bridge for the following reasons:

1. No large earthquake has occurred around the planned bridge construction position. (see Figure 8-11)
2. No seismic acceleration larger than 30 gal has been observed around the planned bridge construction position. (see Figure 8-12)
3. Kh of 0.10 was applied to the bridges in Malawi which were designed and constructed in Grant Aid Cooperation Projects of Japan, including South Rukuru, Bakili Mluzi, Luwazi and Nankokwe Bridges. (see Figures 8-13).
4. The largest seismic acceleration observed around the planned bridge construction position, 30 gal (as mentioned in the above (2)), is converted to a design horizontal seismic scale of Kh = 0.03. However, a figure of 0.1 is the minimum Kh stipulated in the Earthquake Resistant Design Code of Japan.

2) Strengths of Materials

The strengths of various materials to be used in this preliminary design are as follows:

i) Design standard strength of concrete for PC superstructure works

The design standard strength of concrete to be used for PC superstructure works shall be $\sigma ck = 35N/mm^2$.

ii) Design standard strength of reinforced concrete

The design standard strength of reinforced concrete to be used for substructure works, foundation works and reinforcement concrete members, such as curbs and parapet walls, shall be $\sigma ck = 24N/mm^2$.

iii) Design standard strength of plain concrete

The design standard strength of concrete to be used for plain concrete members, such as levelling concrete and caulking concrete for footways, shall be $\sigma ck = 18N/mm^2$.

iv) Reinforcing bars

Reinforcing bars to be used in this project shall satisfy the SD345 specifications.

v) PC steel

The specifications of PC steel to be used on the planned bridge shall be as follows:

Longitudinal: SWPR7BL 12S15.2B

Diagonal: 19S15.2B, 12S15.2B

c) Outline of the Bridge Design

A summary of the design of the planned bridge is given in Table 8-10. Figure 8-14 and Figure 8-15 show the outline design drawings prepared in accordance with the procedures of the preliminary design mentioned above.

Table 8-10 Outline of the Bridge Design

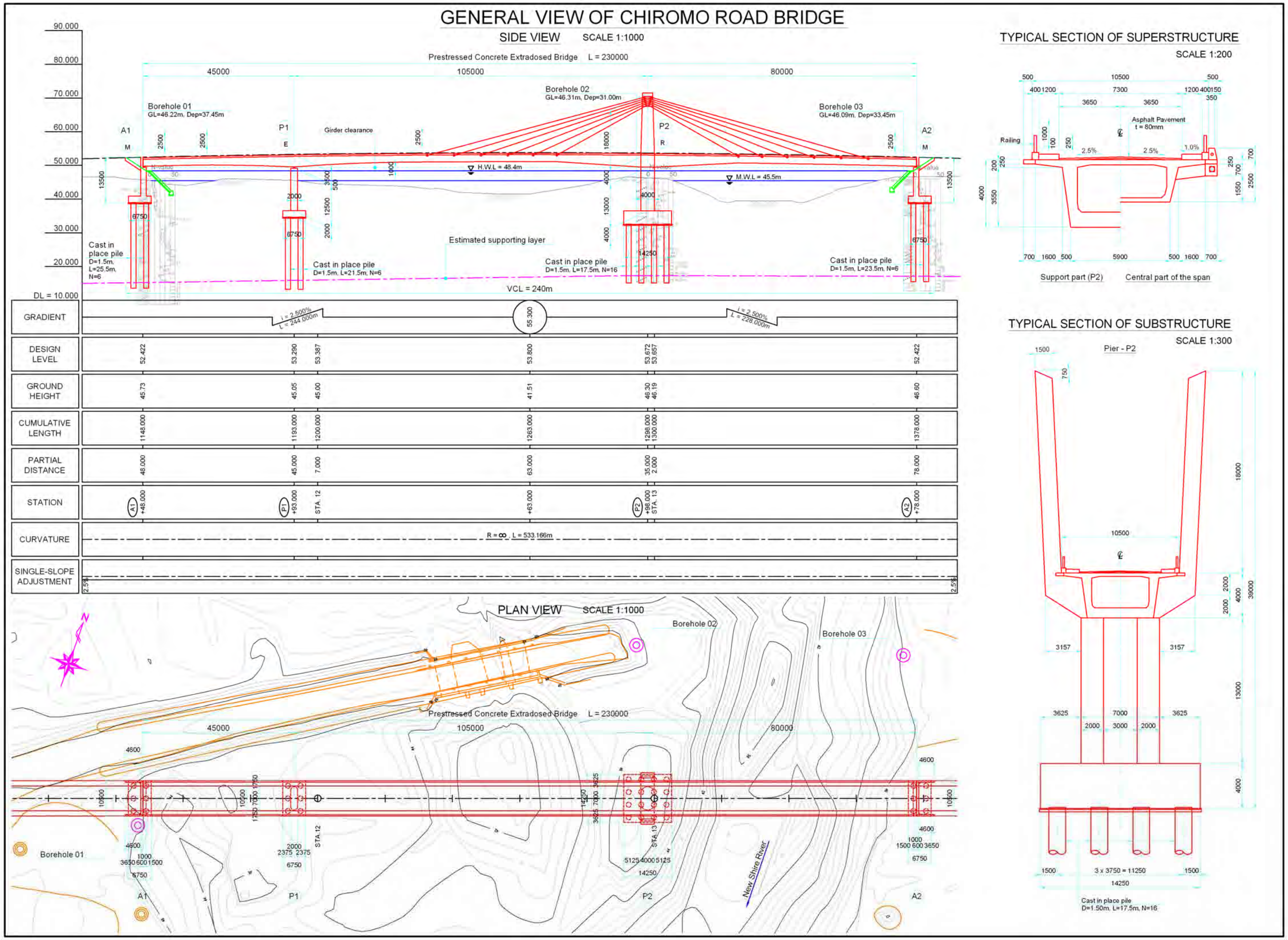
Item		Type / Specifications
Bridge construction position		A position where a bridge crosses over two islands and is connected to the existing road on both sides.
Width	Bridge	Width of carriageway: 3.35 m × 2 = 6.7 m, Bicycle roads: 0.3 m × 2 = 0.6 m, Width of footways: 1.2 m × 2 = 2.4 m, Total: 9.7 m (Effective road width), Curbs: 0.4 m × 2 = 0.8 m and Total: 10.5 m (Total road width)
	Access roads	Width of carriageway: 3.35 m × 2 = 6.7 m, Bicycle roads: 0.3 m × 2 = 0.6 m, Width of footways: 1.2 m × 2 = 2.4 m, Total: 9.7 m (Effective road width) Protective shoulders: 1.0 m × 2 = 2.0 m and Total: 11.7 m (Total road width)
Bridge type		Three-span Extradosed bridge
Bridge length, span lengths		45.0 m + 105.0 m + 80.0 m ＝ 230.0 m
Bridge surface		Asphalt pavement (70 mm on the carriageway)
Abutment A1 (Bangula side)	Type	Inverted T-type Abutment
	Height of structure	13.0 m
	Cast-in-situ concrete pile	Diameter = 1.5 m, Length = 25.5 m, Number of piles = 6
Abutment A2 (Makhanga side)	Type	Inverted T-type Abutment
	Height of structure	13.0 m
	Cast-in-situ concrete pile	Diameter = 1.5 m, Length = 23.5 m, Number of piles = 6
Pier P1	Type	Oval pier
	Height of structure	15.5 m
	Cast-in-situ concrete pile	Diameter = 1.5 m, Length = 21.5 m, Number of piles = 6
Pier P2	Type	Oval pier
	Height of structure	21.0 m
	Cast-in-situ concrete pile	Diameter = 1.5 m, Length = 17.5 m, Number of piles = 16
Access roads	Length	Bangula side: *ca.* 150 m, Makhanga side: *ca.* 100 m
	Surface	Asphalt pavement (surface course: 50 mm)
Revetments	Abutment A1	Wet masonry work
	Abutment A2	Wet masonry work

Source: Study Team

8.2.3 Preliminary Design of New Shire Bridge

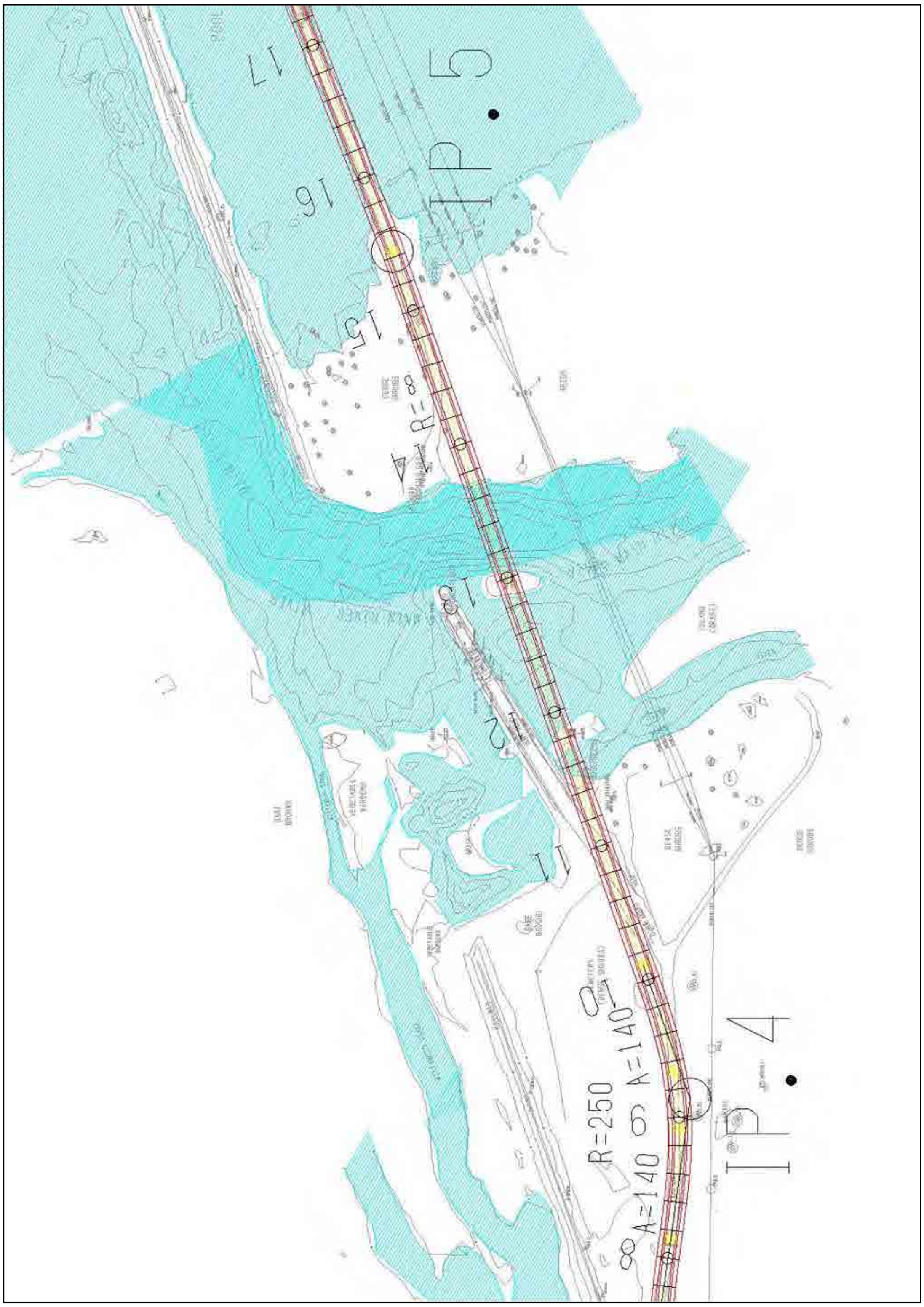
(1) Workflow of the Preliminary Design

In the preliminary design, studies required for the construction of a road bridge downstream of the existing Kamuzu Truss Bridge, including a field survey and studies for the selection of a bridge construction position, road alignment, scale of the bridge and bridge type, will be implemented. The results of these studies will be used to select the best bridge type. Then, the project cost will be estimated. Figure 8-16 shows the workflow of the preliminary design.



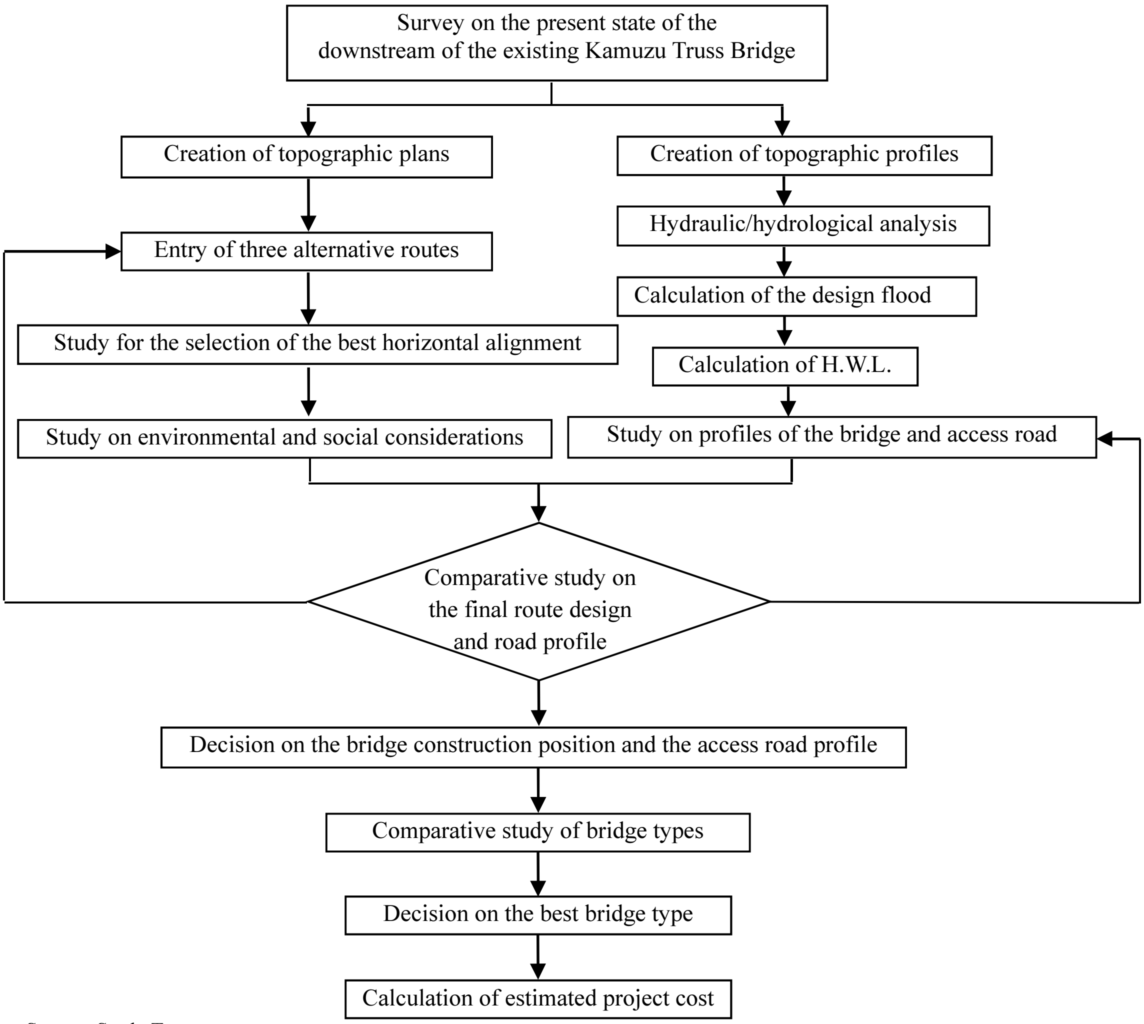
Source: Study Team

Figure 8-14 General Drawing of Chiromo Road Bridge



Source: Study Team

Figure 8-15 Plan of the Access Roads



Source: Study Team

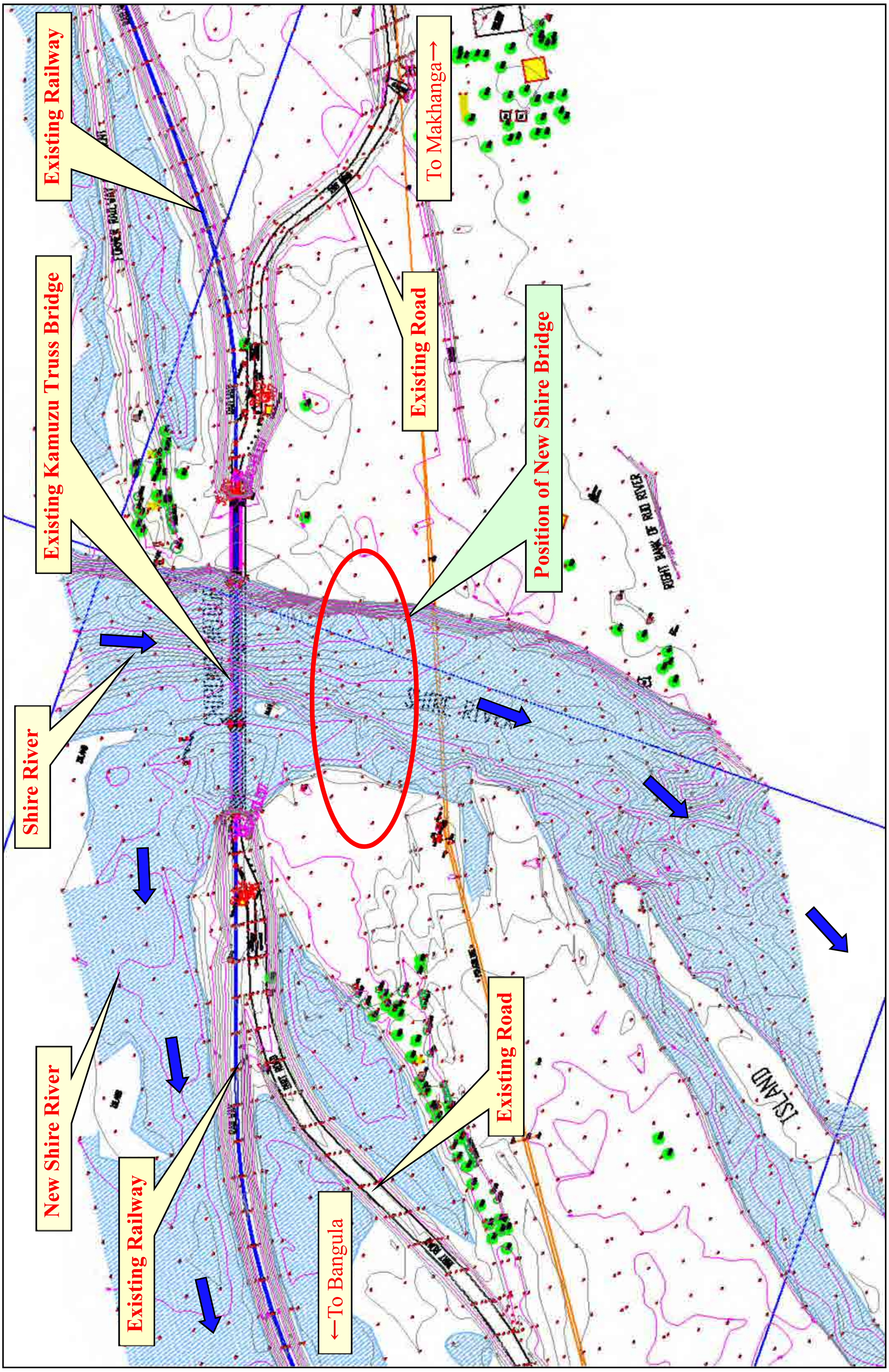
Figure 8-16 Workflow of the Preliminary Design

(2) Present State of the Planned Bridge Construction Position

At present, Kamuzu Truss Bridge spans the Shire River. This bridge was constructed after the flood had washed away the old Kamuzu Truss Bridge in 1949. While it was originally constructed as a railway bridge, it was remodelled as a railway/road bridge after local residents requested that it should also be made available to automobiles. New Shire Bridge is a road bridge planned for construction downstream of the existing Kamuzu Truss Bridge. Figure 8-17 shows the locations of Kamuzu Truss Bridge and planned New Shire Bridge.

(3) Study on the Bridge Construction Position and Access road

The best bridge construction position shall be selected among the three alternatives mentioned below using the results of a comparative study on the bridge construction positions and access road of the three alternatives. In the comparison, the three alternatives are analysed comprehensively, with bridge length, cost-efficiency of bridge construction, alignment of the access road, impact of the Shire River on the access road, flood control measures, land acquisition, construction efficiency and impact on the natural and social environments taken into full consideration, and the best alternative shall be identified from the results of the comprehensive analysis.



Source: Study Team

Figure 8-17 New Shire Bridge Construction Position

a) Alternative 1 (Construct a straight road)

This plan is to construct a bridge in such a way that the Makanga side and Bangula side of the existing road will be connected with a straight alignment road. If this alternative is adopted, while road alignment will be straight, a skew bridge will have to be constructed because of the meandering of the Shire River.

b) Alternative 2 (Construct a bridge with the shortest centre span)

This plan is to construct a bridge at a position where its centre span will be the shortest. If this plan is adopted, there will be two S-shaped curves with small radius on the access road.

c) Alternative 3 (Construct a right bridge)

This plan is to construct a bridge perpendicular to the Shire River. If this plan is adopted, there will be two S-shaped curves with large radius on the access road because of the meandering of the Shire River.

Table 8-11 shows the result of the comparison of the three alternatives above on the basis of the results of the field reconnaissance and topographic surveying.

(4) Comparative Study on Bridge types

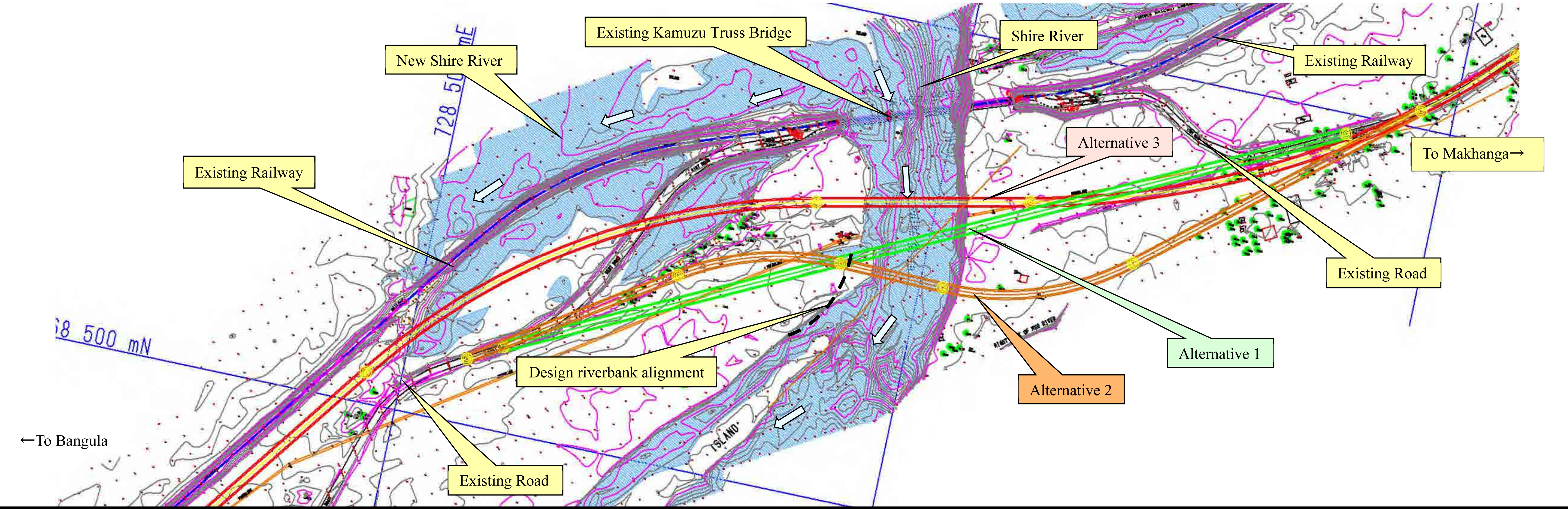
Three types are compared for the bridge to be constructed at the best position selected in (3) above. A concrete bridge shall be the first choice because of its versatility and low material costs. However, a steel bridge shall also be considered as a candidate depending on the span lengths. Regarding the scale of a bridge, bridge length and span length shall be decided using the results of the hydrological survey and analysis of the survey results, and the bridge width shall be the same as the Chiromo Road Bridge (see Figure 8-10).

The following three alternative bridge types shall be compared. Table 8-12 shows the results of the comparative analysis of the three alternatives.

- **Alternative 1:** PC 6-span connected post-tensioned T-girder bridge
- **Alternative 2:** PC 3-span continuous box-girder bridge
- **Alternative 3:** Steel 3-span continuous truss bridge

Figure 8-18 shows the general drawing of Alternative 2 which was selected as the best bridge type.

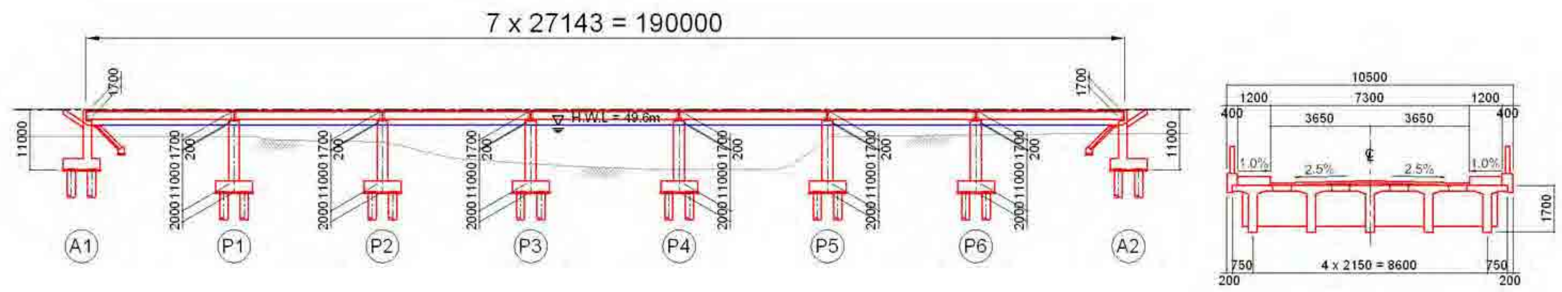
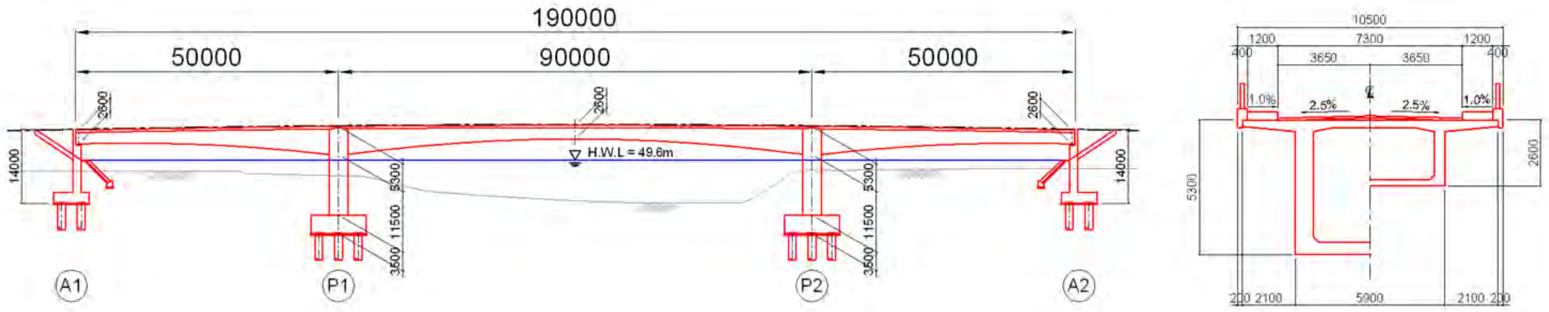
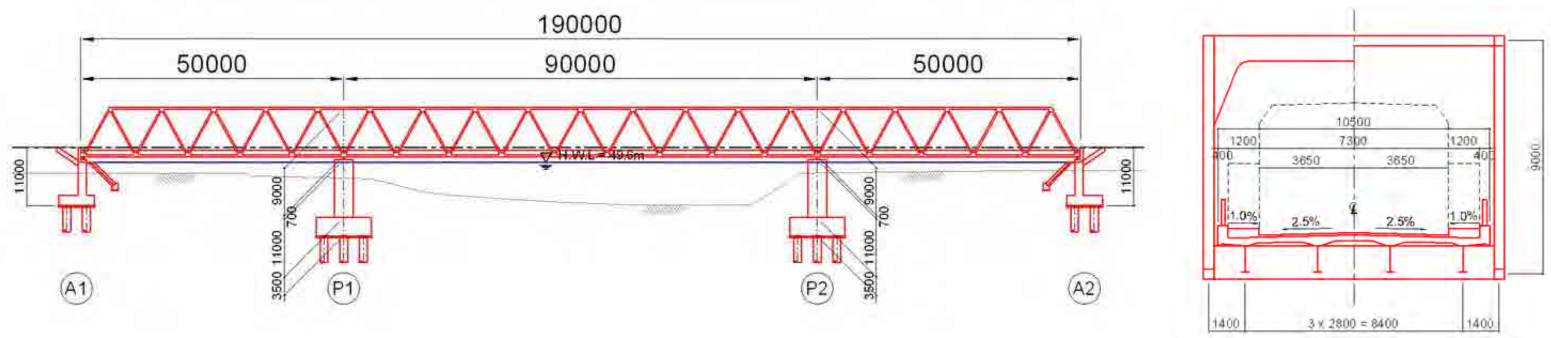
Table 8-11 Comparison of Bridge Construction Position Alternatives



	Alternative	Alternative 1 (construction of a straight road)	Alternative 2 (construction of a bridge with the shortest centre span)	Alternative 3 (construction of a right bridge)
	Overview of alternative	・The Bangula side and the Makhanga side of the existing road will be connected with a straight road	・A bridge will be constructed at a position where its centre span will be the shortest.	・A bridge perpendicular to the Shire River will be constructed.
Evaluation of alternative	Alignment of access road	・ It has the best road alignment among the three alternatives as the alignment of the new access road will be almost straight.	・ Horizontal alignment of the access road will be very poor because of the S-shaped curves on both Makhanga and Bangula sides.	・ Although construction of a right bridge will require S-shaped curves on the access road, the curves will not affect the road alignment significantly as the radii of curve are large.
	Characteristics of new bridge	・ It is structurally not recommendable as it will be a skew bridge. ・ The bridge length (210 m) will be the longest among the three alternatives.	・ The bridge will not have serious structural problem because it is almost a right bridge. ・ Although the length of the centre span of the bridge will be shortest, its total length (190 m) will be the same as Alternative 3.	・ Construction of a right bridge is structurally the most recommendable. ・ The bridge length (190 m) is the same as Alterative 2.
	Impact of the new Shire River on access road	・ Since the access road will be constructed at a relatively high elevation, it will not be significantly affected by flood water from the Shire River.	・ Same as left	・ Although part of the access road on the Bangula side will be constructed in the swamp area, it will not be seriously affected by flood water from the Shire River.
	Flood control measure	・ Design elevation of the access road shall be 49.0 m or above. ・ Revetment works shall be constructed around the abutments.	・ Same as left	・ Same as left
	Environmental and social considerations	・ Since there is no structure in the planned construction area, there will be no need for resettlement of residents or removal of structures.	・ Same as left	・ Same as left
		・ It will be necessary to acquire land for the construction of the access road from the ends of the bridge to where the access roads are connected to the existing road.	・ Same as left	・ Same as left
	Target work (Ratio of costs)	・ Construction of a bridge, access road (a total length of 510 m) and revetments: (1.10)	・ Construction of a bridge, access road (a total length of 550 m) and revetments: (1.00)	・ Construction of a bridge, access road (a total length of 550 m) and revetments: (1.00)
	Overall evaluation	・ The horizontal alignment of the road is the best among the three alternatives, because the new access road will be straight. ・ It is structurally not recommendable as it will be a skew bridge. ・ Construction cost will be the highest as the bridge to be constructed will be longer than the others. ×	・ The S-shaped curves on the access road will make the horizontal alignment of the road extremely poor. ・ The bridge will have no structural problem as it is almost a right bridge. ・ It is extremely cost effective, having the same construction cost as Alternative 3. △	・ Despite the S-shaped curves on the access road, there will be almost no problem as the radii of curve are large. ・ Construction of the right bridge is structurally the most recommendable. ・ It is extremely cost effective, having the same construction cost as Alternative 2. ○

Source: Study Team

Table 8-12 Comparison of Bridge Types

<table>
<tr><th>Bridge type</th><th></th><th>Characteristics</th></tr>
<tr><td rowspan="6"><u>Alternative 1: PC 7-span connected post-tensioned T-girder bridge</u>

</td><td>Structural features</td><td>・A common PC girder bridge that was adopted in many past constructions.
・The connected type offers superior traveling performance and earthquake resistance.</td></tr>
<tr><td>Construction efficiency</td><td>・The new Shire River is five to eight meters deep, making it very difficult to construct bridge piers in the river.
・The adoption of an erection girder enables the construction of the superstructure without influence from the river.</td></tr>
<tr><td>Maintenance performance</td><td>・Since this is a concrete bridge, basically no maintenance is needed.
・Maintenance is needed for bridge accessories such as bearings and expansion joints.</td></tr>
<tr><td>River characteristics</td><td>・Having bridge piers in the river, the bridge has the highest impact on the river.
・The reduction of river cross-section exceeds 6% (standard value: 5%).</td></tr>
<tr><td>Cost efficiency</td><td>・The cost of this bridge type becomes somewhat higher than the alternative 2. (Construction cost ratio: 1.01)</td></tr>
<tr><td>Overall evaluation</td><td>・The construction of bridge piers in the river is very difficult due to water depth.
・ Despite high cost efficiency and maintenance performance, this bridge type had better not be adopted due river cross-section reduction exceeding the standard value.
△</td></tr>
<tr><td rowspan="6"><u>Alternative 2: PC 3-span continuous box-girder bridge</u>

</td><td>Structural features</td><td>・A PC box-girder bridge type appropriate for long spans and adopted in many past constructions.
・The continuous structure offers superior traveling performance and earthquake resistance.</td></tr>
<tr><td>Construction efficiency</td><td>・The construction of bridge piers is easy as they are constructed on river terrace.
・The adoption of the Dywidag method enables the construction of the superstructure without influence from the river.</td></tr>
<tr><td>Maintenance performance</td><td>・Since this is a concrete bridge, basically no maintenance is needed.
・Maintenance is needed for bridge accessories such as bearings and expansion joints.</td></tr>
<tr><td>River characteristics</td><td>・The river cross-section reduction is 4.2%, which is below the standard upper limit.</td></tr>
<tr><td>Cost efficiency</td><td>・This bridge type is the most economic. (Construction cost ratio: 1.00)</td></tr>
<tr><td>Overall evaluation</td><td>・The cost efficiency of this bridge type is the highest.
・The reduction of river cross-section is below the standard value.
・This bridge type is the most desirable alternative in overall evaluation because of cost efficiency, construction efficiency, and river characteristics.
○</td></tr>
<tr><td rowspan="6"><u>Alternative 3: Steel 3-span continuous truss bridge</u>

</td><td>Structural features</td><td>・This bridge type is appropriate for long spans and is adopted when a PC bridge is difficult to implement.
・The continuous structure offers superior traveling performance and earthquake resistance.</td></tr>
<tr><td>Construction efficiency</td><td>・The adoption of the cantilever erection method enables the construction of the bridge without influence from the river.
・The on-site assembly of truss members makes the construction period the shortest.</td></tr>
<tr><td>Maintenance performance</td><td>・Being a steel bridge, there is a problem of corrosion and recoating is needed.
・Maintenance is needed for bridge accessories such as bearings and expansion joints.</td></tr>
<tr><td>River characteristics</td><td>・The river cross-section reduction is 4.2 %, which is below the standard upper limit.</td></tr>
<tr><td>Cost efficiency</td><td>・Being a steel bridge, both the construction and maintenance costs are high, and the cost efficiency is the lowest. (Construction cost ratio: 1.16)</td></tr>
<tr><td>Overall evaluation</td><td>・Being a steel bridge, the maintenance cost is the highest.
・ Although this is a bridge type appropriate for long spans, the cost efficiency is the lowest because it is a steel bridge.
✕</td></tr>
</table>

Source: Study Team

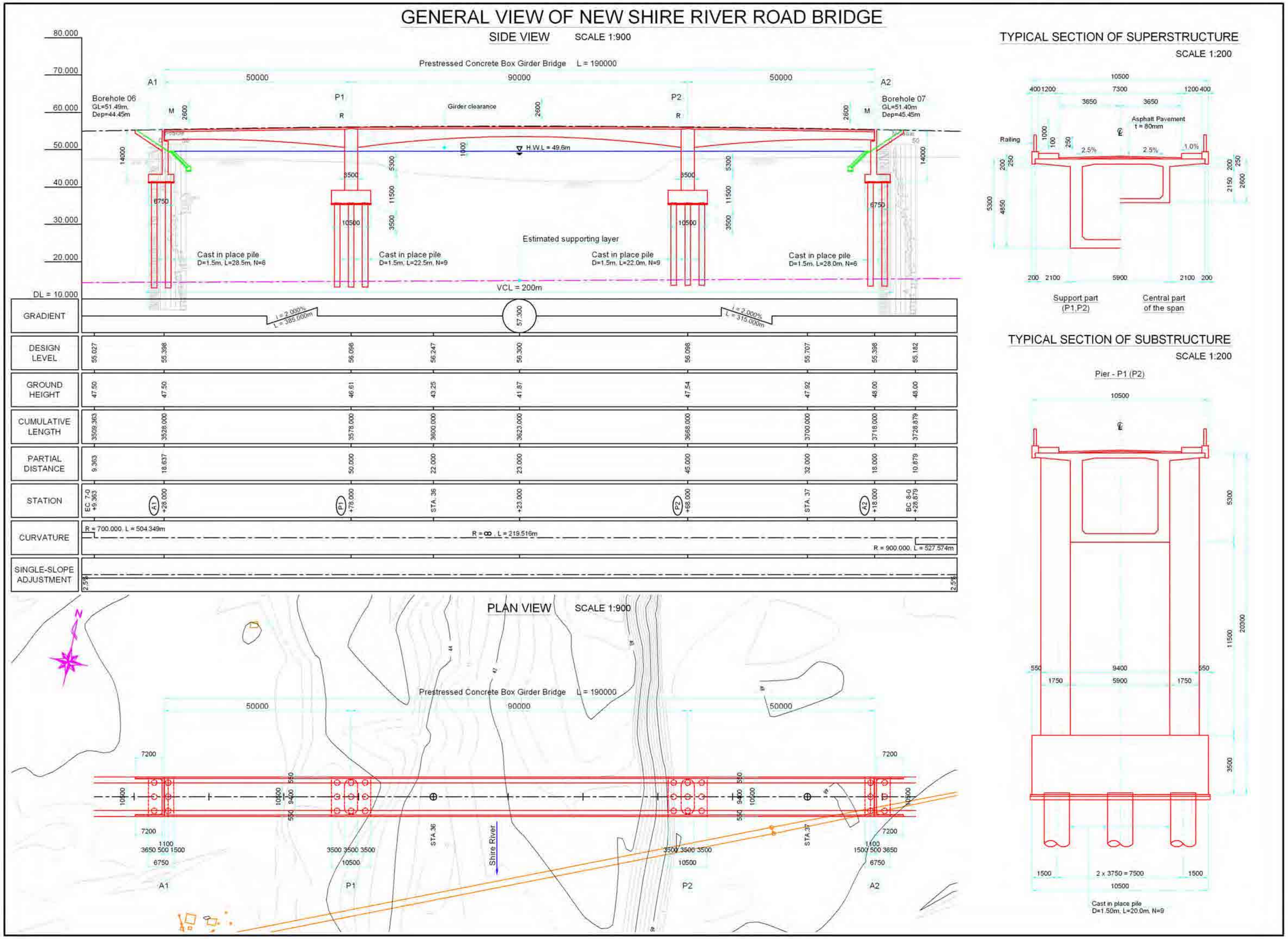


Figure 8-18 General Drawing of New Shire Bridge

8.3 Preliminary Cost Estimation

8.3.1 Basic Policy for Construction of Road and Bridges

This plan is prepared as mentioned below based on the actual conditions.

- The bridges and road will be constructed within the road ROW. In order to construct the new bridges and roads, the Malawi government shall procure the necessary land.
- The construction method shall be applied to avoid the influence of flood in the rainy season.
- The construction of foundation and substructure for bridges shall be done in the dry season in principle.
- Access to the site shall be from the Bangula side. (The completion time of the road construction for S151 is not confirmed yet.) Therefore a temporary bridge shall be built for use during the construction period in order to supply the equipment, material and manpower.
- The procurement period for the material is not steady in Malawi, therefore a leeway for the start of certain work will be necessary.
- The fill material shall be obtained as close as possible to the site from a quarry.

8.3.2 Construction Plan and Procurement Conditions

(1) Preliminary Conditions for Construction Plan

Each work method is mentioned below.

a) Construction of Bridge

1) Concrete Bridge

The planned bridges of Chiromo Road Bridge and New Shire Bridge are PC concrete box girders. In Malawi it is impossible to procure the necessary equipment and material for the mentioned bridges, so those shall be imported from abroad. Also the structural foundation such as a pile or open caisson could be considered and the procurement conditions would be same as for the superstructure of the bridge. For the RC bridge, only the reinforcement bars need to be imported.

2) Truss Bridge

Steel trusses and the launching equipment shall be Fabricated and procured from abroad.

b) Concrete Work

The onsite temperature is high year-round. The maximum daytime temperature only drops below 30°C for two months. A small quantity of concrete could be cast early in the morning or at night. However in order to cast the huge concrete volume such as the footing of the substructure, concrete casting would need to continue during day and night, therefore the concrete temperature would need to be controlled by a cooling plant or ice maker plant.

c) Culvert Work

The Malawi concrete box type uses concrete pipe which is not a hume pipe, and corrugated metal pipes as a culvert structure. To prevent the corrosion of corrugated metal pipes, a bituminous coating is applied to the external surface during road construction between Chikwawa and Bangula. The Contractors do not recommend the use of corrugated metal pipes because of theft or vandalism which could cause the culvert to collapse. Therefore the use of a concrete culvert has been recommended.

d) Embankment Work

The selected material for fill shall be obtained as close as possible to the site and the work shall be carried out as much as possible in the dry season.

e) Pavement Work

The aggregate used for base course and chip seal surfacing for the pavement could be procured in the existing quarry in Blantyre. The major contractors have sufficient construction equipment for paving work. However the bitumen shall be imported from abroad.

f) Temporary Yard

A temporary yard shall be established close to the bridge site on the Bangula side. In this case the land might off the main route, so approval must be obtained from the GoM in order to use it. The purpose of the temporary yard is;

- Site office
- Plant (Concrete)
- Accommodation for workers
- Park for equipment
- Deposit for material
- Work shop for reinforcement bar
- Work shop for form work

(2) Procurement Condition

a) Aggregate

The coarse aggregate used for concrete could be procured in the existing quarry in Blantyre. On the other hand the fine aggregate could be procured near the site. Currently one quarry is being used for the improvement of S515 road between Bangula and Chikwawa. According to the contractor, the amount of useful material might be limited.

b) Cement

The import volume of clinker is extremely decreased and production of cement in Malawi is being suspended. Procurement from Zambia or RSA is presently insufficient, so some contractors are trying to import from another country.

c) Reinforcement Bar and Steel Material

The amount of steel produced in RSA decreased in 2008 and there is a problem of supply shortage, but it is expected that production by major steel companies will resume in early 2012. However, procurement shall be confirmed before the construction begins from RSA or Mozambique as well as from a third country.

d) Bitumen

Just as for reinforcement bars, the procurement is not easy. Sometimes the procurement takes several month. The procurement shall be confirmed before the construction begins from RSA as well as a third country.

e) Material and equipment for Bridge

It is very difficult to procure the material and equipment for bridge construction. The procurement shall be confirmed before the construction begins from RSA as well as a third country.

f) Construction Equipment

Major contractors in Malawi have sufficient equipment for the road construction. However they do not have special equipment for bridge construction. Hence, special equipment shall be procured from abroad.

g) Labour

Some skilled labour could be procured in Lilongwe or Blantyre. Common labour could be procured near the site. However specialists for construction of the foundation or superstructure of the bridge shall be from abroad.

h) Contractor in Malawi

There are more than 10 A-class contractors and they have equipment for road construction mainly and 25ton truck cranes, asphalt plant and concrete plant.

8.3.3 Supervision of Construction by a Consultant

(1) Supervision of Quality Control and Finished Dimension

The quality and finished dimension of each structure shall be kept based on the contract document. The works for the project are PC bridge, RC bridge, steel truss bridges, drainage, earthworks, pavement and miscellaneous structures. For the construction experienced engineers will be needed from other countries.

(2) Supervision of Progress of Works

Prior to starting the project the construction method, equipment, number of labourers shall be studied appropriately and then an adequate program shall be made to avoid any shortage and delay. In case of delay during the construction period, the consultant will order the contractor to modify the plan and the program immediately in order to recover the delay.

(3) Supervision of safety

Accidents on the construction site cause lots of problems and difficulty for the project. So the consultant and contractors shall take necessary measures to avoid any accidents. The contractor shall educate all the labourers in appropriate health and safety procedures.

In case of an emergency, a special organization shall be established prior to the commencement of the work and take the necessary action immediately if accident happens.

On the other hand, to protect the labourers, equipment and construction work from heavy rain and flood, the contractors shall have good knowledge of the weather information and/or forecasting and establish a safety system.

To avoid the traffic accidents and any trouble with third parties, a safety measure plan shall be considered. The plan shall include safety matter of the intersections with public roads, night time, over-loading of transport material, the material logistics and distribution of guards.

(4) Environmental Protection Measures

Mitigation measures against vibration, noise and water contamination shall be considered and controlled by the Consultant and Contractors which shall maintain coordination with local residents.

8.3.4 Estimation of Project Cost

The estimation of construction cost is calculated based on the condition mentioned below. The project cost includes 10% contingency and engineering fee, and does not include tax in Malawi.

- Bridge : Based on the consideration of construction site and structures for Chiromo Road Bridge, New Shire Bridge, those costs are calculated with comparison to similar construction projects abroad. An Extradosed bridge is applied for the Chiromo Road Bridge, and cost is higher than an ordinarily continuous concrete box girder type.
- Road : The completed road construction between Nsanje and Bangula which was signed in 2008 is similar to this subjected project. So those data is referred to in this study. The escalation of construction cost is confirmed at about 16% per annum based on the certificate for payment in the road construction project due to escalated costs for fuel and others construction material. This information is considered in the calculation of construction costs.
- Others : The present situation to accomplish the project due to the shortage of fuel, cement, steel material and asphalt is clearly difficult due to the delay of two Japanese grand aid projects which are still on going. If such difficult conditions could not be solved, the project cannot be completed within the budget and in this situation the start of the project could be put into jeopardy.

Table 8-13 summarises the estimated project cost for the reconstruction of S151 road between Makhanga and Bangula.

Table 8-13 Estimated Project Cost

Cost Item		Estimated Project Cost (US$ million)	
Improvement of Road between Makhanga and Bangula		14.52	
Chiromo Road Bridge	Superstructure works	15.64	22.08
	Substructure works	6.44	
New Shire Bridge	Superstructure works	12.80	19.48
	Substructure works	6.68	
Total Project Cost		56.08	

Source: Study Team

8.4 Establishment of Road and Bridge Maintenance Plan

8.4.1 General

It is vital to ensure that the asset is preserved by timely and effective maintenance. Such maintenance has three principal purposes:

- It prolongs the life of the road and postpones the day when renewal will be required
- It reduces the cost of operating vehicles on the roads
- It helps to keep roads open and ensures greater regularity, punctuality and safety of road transport services

8.4.2 Road Maintenance Plan

(1) Maintenance Activities

Maintenance activities are either cyclic or reactive and can be of a routine or periodic nature. Cyclic activities are those that are carried out at regular intervals. Reactive activities are those that are carried out in response to an occurrence or a condition defect exceeding values dictated by maintenance standards greater than a given value (see Table 8-14).

Many of the activities can be carried out cost-effectively using labour-based methods. If some of the routine maintenance work is contracted on a "lengthman[12] contract" basis, for example, there would be little or no requirement for maintenance labour camps for transport to and from the work site, thereby saving money.

Table 8-14 Maintenance Activities

Works Category	Maintenance Activity	Type	
		Cyclic	Reactive
Routine maintenance	General:		
	Grass cutting	X	
	Removal of obstacles		X
	Culvert clearing/repair		X
	Bridge clearing/repair	X	
	Drain clearing	X	
	Erosion control/repair		X
	Carriageway markings		X
	Repairing road signs		X
	Pavement:		
	Pothole repairs		X
	Surface patching		X
	Crack sealing		X
	Edge repairs		X
Periodic Maintenance	Rejuvenation seal		X
	Resealing		X
	Shoulder regravelling/reshaping		X

Source: SATCC

(2) Maintenance Cost

RA is using these rates in case of Class I Roads Bitumen Surfaced (sealed) for budgeting of routine and periodic activities contained below contained.

[12] Lengthman: A man engaged on a contract basis responsible for routine maintenance on a fixed length of road adjacent to his own home. He is paid a fixed sum per day or month to keep drainage ditches clear, fill in potholes, cut grass, repair minor erosion to shoulders, etc.

Good: US$980 per km/year including grass cutting, ditch and culvert cleaning, patch potholes and others

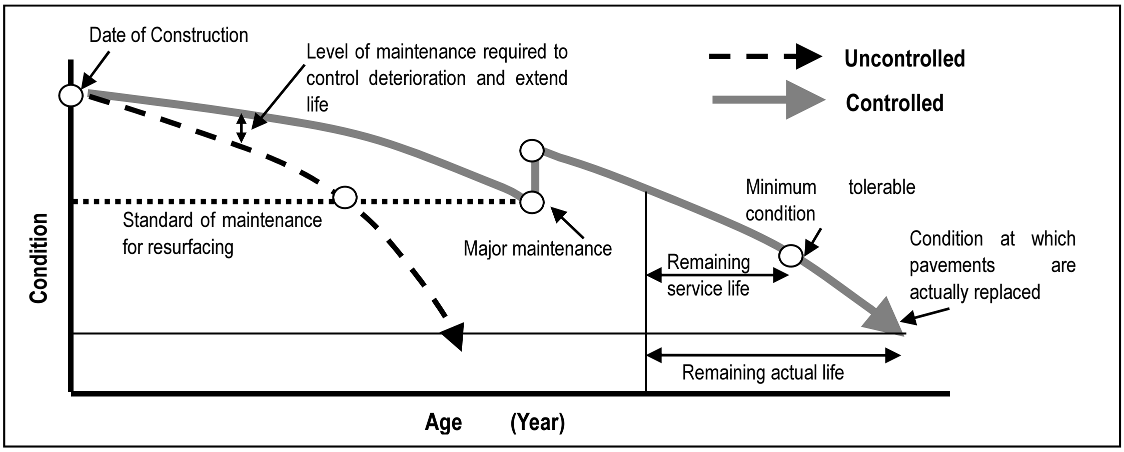
Fair: US$1,445 per km/year including grass cutting, ditch and culvert cleaning, pothole patching, grade shoulders and others

Poor: US$2,330 per km/year including grass cutting, ditch and culvert cleaning, grade shoulders, 2 times patch potholes and others

(3) Consideration of Life Cycle

Even with strict adherence to proper standards of construction, roads deteriorate with the passage of time. The rate of deterioration may vary greatly depending on the climate, the strength of the pavement and underlying subgrade, the traffic volume and axle loads. The wear and tear of road surfaces by traffic is aggravated by rainwater and by changes in temperature. Cracking occurs in the bituminous surfacing which, together with the ingress of rainwater, often leads to pavement failures.

When a double surface dressing (DBST) for design road are adopted, it is proposed to conduct slurry seal work as major maintenance at after 10 years form start of service. (see Figure 8-19)



Source: Study Team

Figure 8-19 Deterioration of Road Condition by Timing

8.4.3 Bridge Maintenance Plan

The GoM will be in charge of the implementation and management of this project. The management of bridges is the responsibility of regional offices of RA, and the Southern Regional Office of RA takes charge of this project. While maintenance works was previously performed by the provincial office of MoTPI, these are now outsourced by RA to private firms selected by bidding. The maintenance works after the completion of this project is generally divided into those performed regularly every year and those performed at intervals of several years. The following works are needed for this project.

(1) Inspection and Maintenance Needed Every Year

- Removal of sand and dirt accumulating in bridge deck drain pipes, the areas around bearings, gutters and other drain facilities, and cleaning of these areas.
- Maintenance of traffic safety facilities including re-application of surface signs.
- Inspection and repair of bank protection and riverbed protection works after floods.
- Removal of boulders, driftwood, etc. after floods.

(2) Maintenance Performed at Intervals of Several Years

- Patching or overlaying of bridge deck pavement; at intervals of about 5 years.
- Replacement of expansion joints; at intervals of about 10 years.

Because bank protection and riverbed protection works are important for bridge maintenance in this project, these structures are designed based on the design flood flow probability of one flood every 50 years. However, these structures are subject to the risk of collapse and being washed away as a result of unpredictable localized erosion or a flood exceeding the assumed probability. Therefore, MoTPI and RA are requested to establish a system so that relevant departments will be able to perform inspection promptly after a flood and MoTPI and RA will be able to promptly repair any damage, failure, etc. in these structures. If left untreated, such conditions may lead to backfill earth behind abutments being washed away, leading to subsidence of the abutments and disruption of traffic in the worst case.

(3) Operation and Maintenance Cost

Maintenance and management of the new bridge to be constructed by this Project will be undertaken by RA, which contracts private companies to maintain bridges using the budget appropriated by the government. As shown in Table 12-15, the maintenance works required after completion of Chiromo Road Bridge consist of daily inspection, cleaning, and repair, the cost of which is estimated at MWK 4,064 thousand on the annual average. This is only 0.06% of RA's total maintenance budget of MWK 7,288,746 thousand (2010/2011), which can amply cover the maintenance cost of the Project.

8.5 Economic Analysis of Reconstruction of S151 Road between Makhanga and Bangula

8.5.1 Methodology of Economic Analysis using HDM-4 Model

The economic analysis of the reconstruction of S151 Road between Makhanga and Bangula is conducted using the Highway Development and Management (HDM-4) model of an economical evaluation model. The HDM-4 is generally applied to the evaluation of road projects in Malawi by RA. The development of HDM-4 was sponsored by several agencies including the World Bank and Asian Development Bank.

Table 8-15 Major Bridge Maintenance Items and Cost

Category	Frequency	Parts requiring inspection	Description of work	Estimated cost (MWK thousand)		Remarks
				Per maintenance once	Per annum	
Maintenance and management of drainage system	Twice a year	Bridge deck drainage	Sediment removal	9	18	
		Gutters	Sediment removal	149	298	
Maintenance and management of traffic safety facilities	Once a year	Markings	Re-coating	319	319	Assuming restoration of 10% of direct cost
Inspection and repair of bank and riverbed protection works	At the time of flood (assumed to be once in 2years)	Bank and riverbed protection	Repair of damaged parts	2,657	1,329	Assuming restoration of 2% of direct cost
Maintenance and repair of pavement	Once in 5 years	Pavement surface	Overlaying, repair of pavement cracks, potholes, etc.	5,644	1,129	Assuming restoration of 10% of direct cost
Exchange of bearings and expansion joints	Once in 10 years			9,709	971	direct cost, removal cost and overhead charge
The above maintenance cost as an annual average					4,064	

Source: Study Team

The main benefits calculated by HDM-4 relate to savings in vehicle operating cost (VOC) derived from reduced roughness on the road, savings in passenger travel time cost (TTC) derived from increase in speed due to improved road conditions, reduction in road accident cost and reduction in maintenance cost due to the complete repair of the existing road.

In this HDM-4 analysis, Economic Internal Rate of Return (EIRR), Benefit and Cost Ratio (B/C Ratio) and Economic Net Present Value (ENPV) are estimated as economical evaluation indexes. The methodologies of these indexes are as follows.

(1) Economic Internal Rate of Return (EIRR)

The EIRR is the discount rate where total benefits and total costs calculated into the net present value become equal. The EIRR is evaluated in comparison to the opportunity cost of capital. In the analysis, the Social Discount Rate (SDR) of 12.0% is applied as the opportunity cost of capital. In Malawi, SDR of 12.0% is widely applied in the analysis of infrastructure projects conducted by international agencies.

(2) Benefit and Cost Ratio (B/C Ratio)

The B/C ratio is the ratio found from the net present value of the total benefit divided by the net present value of the total cost. The advantage of the project is evaluated from the value of this ratio, and if the ratio is higher than 1.00 under the designated discount rate, this project is considered to be socially and economically viable. The SDR to be applied for the evaluation of B/C ratio is normally decided by the opportunity cost in the country concerned. Same as EIRR, the SDR=12.0% is applied as the discount rate in the analysis.

(3) Economic Net Present Value (ENPV)

The ENPV is the total net benefit found from the difference between total benefit and total cost in net present value. The advantage of the project is evaluated from the amount of ENPV. The ENPV is discounted by the SDR=12%.

8.5.2 Premises

In the Study, the economic analysis is carried out based on the following premises.

(1) Period of the Analysis

The period of the analysis is set for 20 years from 2015 to 2035.

(2) Discount Rate

As mentioned in Chapter 8.5.1, social discount rate of 12.0% is applied as the discount rate in the analysis. Therefore all project costs and benefits have been discounted back to 2015 at 12.0% to be expressed as present values of that year.

(3) Exchange Rate

The exchange rate is assumed to be US$1.00 = MWK165.00 = JPY78.60 as monthly average of November 2011. All costs are given in US$.

(4) Economic Price

All figures are based on constant prices in 2011. The economic prices are calculated excluding transferable items such as various taxes, customs duty and subsidies etc., from the viewpoint of the national economy. In order to translate market price into economic price, Standard Conversion Factor (SCF) is applied in economic analysis. In Malawi, Value Added Tax (VAT) of 16.5% is applied to all materials and equipment. On the other hands, customs duty and other excise duties are free (0%) for relevant materials of road project. Thus, SCF is given as 1/1.165 = 0.85.

(5) Inflation

Since it is difficult to estimate the inflation rate during the overall period of the project, it is not considered in the analysis.

(6) Residual Value

The life cycle of the road is 25 years, and that of structure such as bridge is 50 years. The residual value in the last year (2035) of the analysis is counted as the negative investment cost. Therefore the residual value of the road asset is 20%, and the bridge is 60% of the initial investment has been credited in the final benefit year.

(7) Shadow Prices

Shadow pricing in project appraisal is often recommended as a means of correcting for economic distortions. But in this analysis, it was decided that it would be inappropriate to use shadow prices for the following reasons:

- Studies elsewhere have found that shadow pricing makes little difference to the analysis of projects such as the Zomba- Blantyre road. Changes in costs are generally balanced by similar changes in benefits. The import content of construction is similar to that of vehicle operating costs. The proportion of unskilled labour in total construction costs is small, and similarly unskilled labour is a small component of total vehicle operating costs.

- The rate of return would be little affected by shadow pricing cost inputs. More significant changes would result if project benefits were weighted according to a distribution index, but the GoM has been consistently concerned with total benefits rather than their distribution between different groups.
- One of the major reasons for shadow pricing is a distorted labour market where wages exceed the economic opportunity cost of unskilled labour. Unlike many countries, Malawi has limited unskilled wage rates and the financial and economic costs of unskilled labour are unlikely to differ substantially.
- Overvalued exchange rates are also a common reason for using shadow prices. The MWK has depreciated significantly in recent years, and with the present debt service ratio and outlook for exports this depreciation could continue. Improvements to the external transportation system would, however, improve the situation significantly.

8.5.3 Input Data for HDM-4

To conduct HDM-4 analysis, following (1) to (5) data related to vehicle operating cost (VOC) and (6) for passenger travel time cost (TTC) are defined.

(1) Price of Vehicles

The cost of new vehicle is an essential input to HDM-4 since other aspects of VOC depend upon the values of vehicles, including maintenance costs, depreciation and interest. Table 8-16 shows economic and financial prices of different type of vehicles.

Table 8-16 Economic and Financial Prices of Different Type of Vehicles

Vehicle Type	Standard Vehicles	Economic Cost (US$)	Taxes	Financial Cost (US$)
Private car	Toyota Corolla	26,389	42%	37,472
Rural vehicle	Toyota Hilux	27,083	27%	34,395
Mini bus	Toyota Hiace	43,448	30%	56,482
Bus	Nissan Diesel 70 seater bus	179,414	0%	179,414
Light truck	Mazda 3 tonnes	60,348	15%	69,400
2-axle truck	Nissan 10 tonnes	102,755	15%	118,168
3-axle truck	Mitsubishi 15 tonnes	106,017	10%	116,619
Heavy truck	Mercedes Benz 40 tonnes	122,328	5%	128,444

Source: Toyota Malawi, Malawi Motors, Stansfied Motors Ltd., Customs and Excise Tariff Book (2005)

(2) Price of Fuel

The price of fuel is the most significant determinant of VOC's, so it is important to accurately determine its true economic price. The price of fuel is subjected to a range of duties, charges and levies in addition to wholesale and retail margins. Table 8-17 shows the breakdown of duties, taxes and levies as of March 2011. One of the levies is the Price Stabilization Fund (PSF). This PSF ensures that the price of fuel in Malawi does not fluctuate as widely as world market prices. Thus, it is easy to estimate the price increase in fuel for a number of years by considering the percentage price increase of fuel in recent years.

Table 8-17 Fuel Price Build-up (8th November 2011)

Item	Fuel Price (MWK)		Fuel Price (US Cents)		Share (%)	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
FOB	6,430.65	6,902.32	38.87	41.72	16.92	19.17
Railage	71.97	72.84	0.44	0.44	0.19	0.20
Road Freight	1,270.65	1,222.14	7.68	7.39	3.34	3.39
Insurance/Handling	87.60	85.37	0.53	0.52	0.23	0.24
Losses	51.40	52.91	0.31	0.32	0.14	0.15
In Bond Landed Cash (Blantyre/Lilongwe)	7,912.27	8,335.58	47.83	50.39	20.82	23.15
Energy Regulatory Levy	200.00	200.00	1.21	1.21	0.53	0.56
Road Levy	2,870.00	2,370.00	17.35	14.33	7.55	6.58
Malawi Bureau of Standard Cess	15.82	16.67	0.10	0.10	0.04	0.05
Safetynet Levy	1,982.00	1,982.00	11.98	11.98	5.22	5.51
Rural Electrification Levy	1,710.00	1,620.00	10.34	9.79	4.50	4.50
Price Stabilization Fund	15,548.95	13,994.16	93.99	84.60	40.92	38.87
Storage Levy	500.00	500.00	3.02	3.02	1.32	1.39
Duty Free Price	30,739.04	29,018.41	185.82	175.42	80.89	80.61
Duty	791.23	833.56	4.78	5.04	2.08	2.32
Excise Duty	2,524.02	2,750.74	15.26	16.63	6.64	7.64
Duty Paid Price	34,054.29	32,602.71	205.86	197.08	89.62	90.56
Distribution Margin	233.00	233.00	1.41	1.41	0.61	0.65
Gross Margin	1,903.19	1,450.00	11.50	8.77	5.01	4.03
Wholesale Price	36,190.48	34,285.71	218.77	207.26	95.24	95.24
Retail Margin	1,809.52	1,714.29	10.94	10.36	4.76	4.76
Pump Price	38,000.00	36,000.00	229.71	217.62	100.00	100.00
MWK per Litre	380.00	360.00	229.71	217.62	1.00	1.00

Source: Malawi Energy Regulatory Authority (MERA)

(3) Vehicle Maintenance Cost

The costs of vehicle maintenance are estimated in HDM-4 with the labour and material costs, separately. Maintenance parts costs are estimated as a percentage of the value of the new vehicle. This is based upon the relationship between the age of the vehicle, its value and the roughness of the road. Maintenance labour cost is based upon the amount of maintenance parts used. HDM-4 thus contains a relationship between maintenance parts and the amount of labour required to repair the vehicle. In this study, the cost of labour has been estimated from known charges at local garages as around MWK 3,000.00 per hour.

(4) Crew Costs

The cost of paid crew has been estimated based upon average rates for employment. The average number of crew in each type of vehicle has been estimated based upon observed practice and the results of previous feasibility studies. The results of these calculations are given in Table 8-18.

Table 8-18 Crew Costs

Item	Passenger Car	Pick-up	Minibus	Large Bus	Light Truck	Medium Truck	Articulated Truck*	Truck Trailer
Crew cost/hour (MWK)	85	85	85	100	100	100	100	100
Crew cost/hour (US$)	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Number of crew	0	0.75	2	2	1	1	1	1
Total crew cost per veh. hr. (MWK)	0	63.75	170	200	100	100	100	100
Total crew cost per veh. hr. (US$)	0.00	0.45	1.21	1.42	0.71	0.71	0.71	0.71

Note: Articulated truck – Semi trailer
Source: RA

(5) Overhead Costs

The average annual overhead costs include insurance, certificate of fitness and road tax. Table 8-19 shows the overhead costs for each type of vehicle.

Table 8-19 Overhead Costs

Item	Passenger Car	Pick-up	Minibus	Large Bus	Light Truck	Medium Truck	Articulated Truck*	Truck Trailer
Certificate of fitness	1,000	1,000	4,000	4,000	1,000	1,000	1,000	1,000.
Road tax	5,000	5,000	12,000	12,000	16,000	16,000	18,000	36,000
Insurance	13,200	15,000	41,000	17,500	17,500	17,500	17,500	20,400
Total in MWK	19,200	21,000	57,000	33,500	34,500	34,500	36,500	57,400
Total in US$	136.17	148.94	404.26	237.59	244.68	244.68	258.87	407.09

Note: Articulated truck – Semi trailer
Source: RA

(6) Passenger Travel Time Cost

The passenger travel time cost (TTC) savings have been assessed referring previous studies. Average incomes were used as the basis for the Value of Time (VoT), and were assessed from the GoM's publications. It has been assumed that work travel time is valued at 50% of hourly wage and, non-work travel time is valued at 25%. Vehicle occupancy has been derived from a number of sources, including observation. Table 8-20 shows passenger travel time cost for each type of vehicle.

Table 8-20 Passenger Travel Time Cost

Item	Passenger Car	Pick-up	Minibus	Large Bus	Light Truck	Medium Truck	Articulated Truck*	Truck Trailer
Average wage for passenger/month (MWK)	25,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Hourly wage (MWK)	150.60	60.24	60.24	60.24	60.24	60.24	60.24	60.24
Proportion of work trips	35%	35%	10%	10%	25%	25%	25%	25%
Value of work travel time (MWK)	75.30	30.12	30.12	30.12	30.12	30.12	30.12	30.12
Value of non-work travel time (MWK)	37.65	15.06	15.06	15.06	15.06	15.06	15.06	15.06
Number of passenger/vehicle	3	3	16	50	1	1	1	1

Note: Articulated truck – Semi trailer
Source: RA

8.5.4 Definition of Cases for Analysis

In the analysis, the cost and the benefit are defined as the difference between "Without the project" and "With the project" cases. The cases are assumed as follows.

(1) "Without the project" Case (Option-0)

In this case, it has been assumed that no major investment is going to take place; hence maintenance of the current road network infrastructure would be carried out annually.

In the do nothing case, the existing roads were classified as bumpy, narrow in some parts, numerous potholes. A certain level of periodic maintenance was assumed, but not upgrading of the roads.

(2) "With the project" Case (Option-1 and Option-2)

In the "With the project" cases, the project road would be upgraded to a class 1 bitumen standard with an initial roughness of around 2 mm/km. The project road has three major components as follows.

- Reconstruction of S151road between Makhanga and Bangula (8.5km)
- Construction of a road bridge at Chiromo
- Construction of a road bridge at Shire

Under the Option-1, it was assumed that the S151 road between Makhanga and Bangula would be reconstructed at a cost of US$ 14.52 million together with the construction of Chiromo Road Bridge at a cost of US$ 22.80 million and also the construction of New Shire Bridge at a cost US$ 19.48 million. The total investment cost is US$ 56.08 million. Under the Option-2, it was assumed that the S151 road between Makhanga and Bangula would be reconstructed at a cost of US$ 14.52 million together with the construction of Chiromo Road Bridge at a cost of US$ 19.48 million. The total cost is US$ 36.60 million.

8.5.5 Results of Economic Evaluation

(1) Results of the Economic Evaluation by HDM-4 model

The main tool used in the economic evaluation was the World Bank's HDM-4 model. Results of the main run based on central forecasts for capital costs, maintenance cost, traffic volumes and vehicle operating costs.

The basic economic requirement for the project to be deemed economically feasible by the Malawi government is that it should have an EIRR of at least 12% of social discount rate. It should be pointed out that three engineering options are considered and evaluated and the results are presented in Table 8-21.

Table 8-21 shows that both engineering solutions are economically viable, however, Option -2 which includes improvement of S151 road between Makhanga and Bangula, and construction of only the Chiromo Road Bridge is the highest EIRR value of 50%, compared with Option-1, which includes improvement of S151 road between Makhanga and Bangula, and construction of both the Chiromo Road Bridge and the New Shire Bridge with EIRR value of 26.0%.

Table 8-21 Results of Evaluation of Basic Options

(Social discount rate = 12.0%)

	Engineering Option	Total Investment Cost (US$ million)	Economic Internal Rate of Return (EIRR)	Benefit and Cost Ratio (B/C Ratio)	Economic Net Present Value (ENPV) (US$ million)
1	Without Project	0.547	0.0%	0.0	0.000
2	With Project (Option-1) (Road improvement and Construction of Chiromo Road Bridge and New Shire Bridge)	42.358	26.0%	1.697	71.876
3	With Project (Oprion-2) (Road improvement and Construction of only Chiromo Road Bridge)	28.005	50.0%	6.421	179.831

Source: Study Team

(2) Sensitivity Analysis

Sensitive analysis was carried out where construction costs were increased by 20%, and then traffic growth was reduced by 50%. The worst case scenario of combined sensitivity of the two was also carried out and the results are shown in Table 8-22.

Table 8-22 Results of Sensitivity Analyses

Traffic Growth \ Cost	0%	+20%
Option-1		
0%	26.0%	22.9%
-50%	16.6%	14.2%
Option-2		
0%	50.0%	44.7%
-50%	41.9%	37.0%

Source: Study Team

Based from the above analysis, Option-1, the improvement of road section between Makhanga and Bangula with the construction of the Chiromo Road Bridge and the New Shire Bridge, is technically and economically viable, but at the worst case scenario the EIRR is near marginal at 14.2%.

On the other hand, Option-2, the improvement of road section between Makhanga and Bangula road section with the construction of only the Chiromo Road Bridge yields the highest Economic Internal Rate of Return; moreover at the worst case scenario the EIRR is 37.0%. However, under this option, serious problem of one-way traffic as well as waiting time for passage of trains on the Kamuzu Truss Bridge, which drastically decrease the traffic capacity of S151 road between Makhanga and Bangula, will still remain.

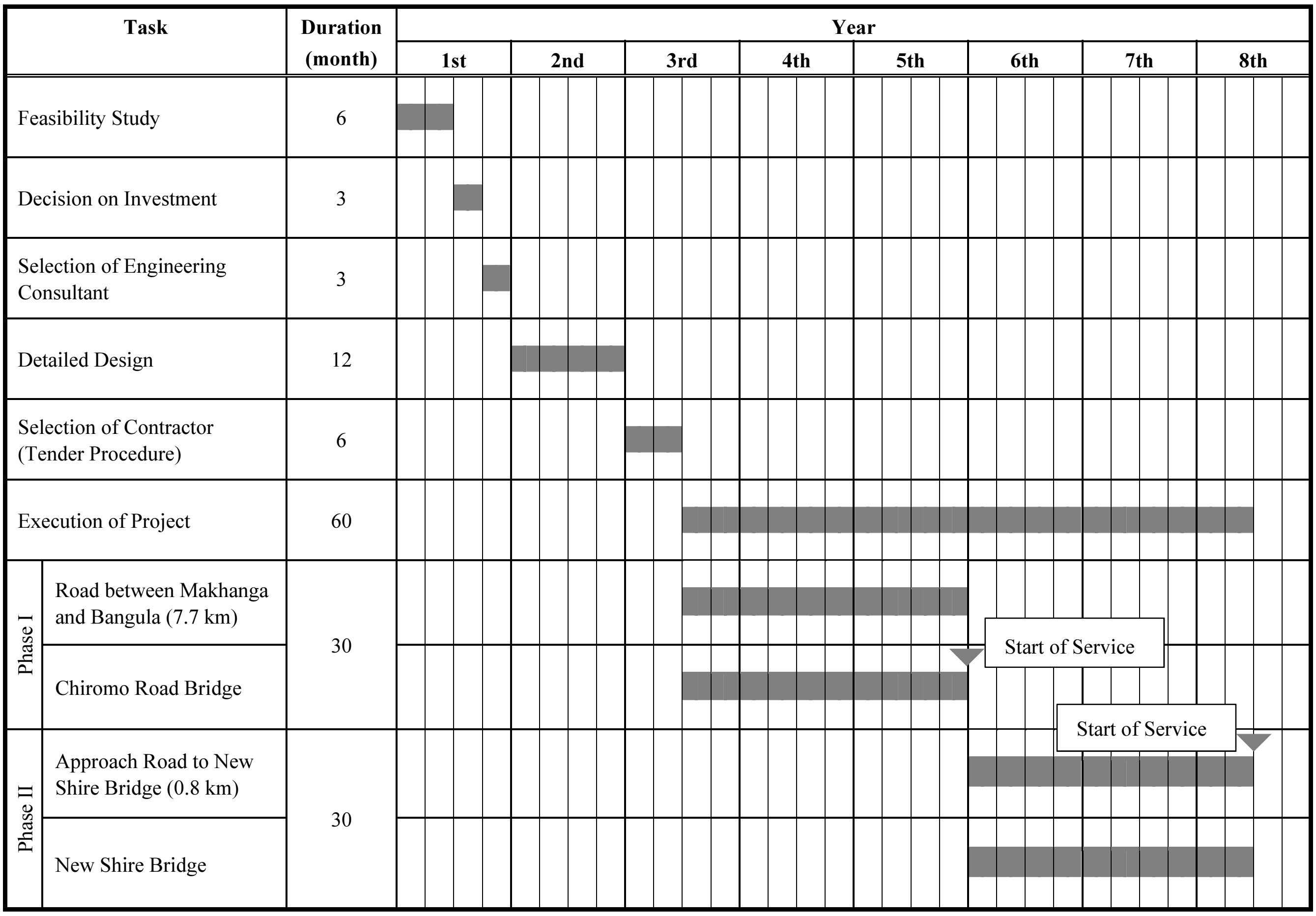
This therefore would need further confirmation by robust economic evaluation at the full feasibility study stage to be conducted later.

8.6 Implementation Programme for Reconstruction of S151 Road between Makhanga and Bangula

The implementation schedule for the rehabilitation of the S151 road between Makhanga and Bangula is as follows. The project is divided into two phases which comprise Phase 1; the construction of a road between Makhanga and Bangula (7.7 km) including the Chiromo Road Bridge, and Phase 2; the construction of an approach road (0.8 km) to the New Shire Bridge including the new bridge. Service between Makhanga and Bangula is assumed to begin five years from the start of the Feasibility Study, and then a full two-way service is assumed to begin two and a half years after the completion of Phase 1 (see Table 8-23).

- Feasibility Study: 6 months
- Decision on Investment: 3 months
- Selection of Engineering Consultant: 3 months
- Detailed Design: 12 months
- Selection of Contractor: 6 months
- Execution of Project: 60 months
  30 months for the Phase 1
  30 months for the Phase 2

Table 8-23 Implementation Schedule



Source: Study Team

8.7 Overall Evaluation of Reconstruction of S151 Road between Makhanga and Bangula

Overall evaluation of the reconstruction of S151 road between Makhanga and Bangula summarized as follows:

(1) Expected Economic Benefits of the Project

The S151 road between Makhanga and Bangula is currently disconnected at the Chiromo wash away and not functioning as a road for vehicular traffic. Reconstruction of road sections as well as the construction of two bridges would provide several benefits to the national and local economy, such as the function of providing alternative arterial road access between the Lower Shire area the Highland area, that currently depends only on M1 with a steep gradient section. This function is also very important from the national security point of view to secure a redundancy of transport route in the Southern Region of Malawi.

Construction of the Chiromo Road Bridge will generate a very positive economic and social benefits for residents such as to bring and sell agricultural products in Bangula, the ability to commute to school and better health care services. This would be particularly beneficial to those living on the eastern side of the New Shire River who have been forced to use an expensive and risky boat crossing since the disconnection of the S151 in 1997.

(2) Improvement of Road Section between Makhanga and Bangula

For the planning of horizontal and vertical alignment of road section, alternative routes are compared to minimize the necessity for resettlement of houses and shops, as well as to secure the function of an all-weather road by sufficient height of embankment to prevent damage to the road by frequent floods from the Ruo River and the New shire River. The horizontal alignment in Makhanga area is planned to avoid resettlement of 16 houses/shops near the railway crossing. Also, a selected alternative route is planned to avoid the high risk from the Ruo River bank erosion, where the existing road is only 30 m from the continuously eroding river bank.

(3) Construction of the Chiromo Road Bridge

The Chiromo Road Bridge is planned to cross the Chiromo washed away section by the best horizontal alignment not only from the geometric design point of view, but also to avoid negative influence on the planned railway line alignment, also proposed in the Study. The type of structure is selected by comparing structural features, girder height, embankment height and cost performance. As a result, the Extradosed type 3 spans PC Box Girder Bridge was selected as the most suitable type.

(4) Construction of the New Shire Bridge

The Shire Bridge is planned to cross the Shire River in parallel with the existing Kamuzu Truss Bridge, which was originally constructed exclusively as a railway bridge, and converted into railway-cum-road bridge after installing open grating floors. In order to avoid traffic confusion on this Kumuzu Truss Bridge after completing the improved road section between Makhanga and Bangula, and construction of the Chiromo Railway Bridge, as well as reconstruction of the railway between Makhanga and Bangula, construction of the New Shire Bridge only for road traffic is evaluated as a priority project for the medium term project after completion of those components of the road project.

(5) Economic Analysis

In the economic analysis, all the values of the evaluation index are in good standard and this project is considered to be economically feasible from the viewpoint of the national economy, even though this is a full scale project, including road improvement as well as construction of two new bridges.

(6) IEE Results

According to the scoping results of the project, executing the project will generate various positive impacts particularly for the local economy and social lives of local residents. On the other hand, negative effects under the environment and social consideration are very limited. Mitigation measures for these limited negative impacts should be studied in detail when the horizontal alignment of the road for improvement will be more concrete under the feasibility study stage.