Ministry of Transport and Public Infrastructure

The Republic of Malawi

PREPARATORY SURVEY REPORT
ON
THE PROJECT FOR
REPLACEMENT OF SOUTH RUKURU BRIDGE
ON THE MAIN ROAD NO.1
IN
THE REPUBLIC OF MALAWI

November 2009

JAPAN INTERNATIONAL COOPERATION AGENCY

CENTRAL CONSULTANT INC.

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Preface

Japan International Cooperation Agency (JICA) conducted the preparatory survey on the project for replacement of South Rukuru Bridge on the Main Road No.1 in the Republic of Malawi.

JICA sent to Malawi a survey team from February 23 to April 14, 2009.

The team held discussions with the officials concerned of the Government of Malawi, and conducted a field study at the study area. After the team returned to Japan, further studies were made. Then, a mission was sent to Malawi in order to discuss a draft outline design, and as this result, the present report was finalized.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Malawi for their close cooperation extended to the teams.

September 2009

Toshiyuki Kuroyanagi
Director General,
Economic Infrastructure Department,
Japan International Cooperation Agency

Letter of Transmittal

We are pleased to submit to you the preparatory survey report on the project for replacement of South Rukuru Bridge on the Main Road No.1 in the Republic of Malawi.

This survey was conducted by Central Consultant Inc., under a contract to JICA, during the period from February 2009 to December 2009. In conducting the survey, we have examined the feasibility and rationale of the project with due consideration to the present situation of Malawi and formulated the most appropriate outline design for the project under Japan's Grant Aid scheme.

Finally, we hope that this report will contribute to further promotion of the project.

Very truly yours,

Teruo Nakagawa
Project manager,
Preparatory Survey team on
the project for replacement of South Rukuru Bridge on the Main Road No.1
Central Consultant Inc.

Summary

(1) Overview of the Country

The Republic of Malawi (hereinafter referred to as “Malawi”) is an inland nation situated in Southern Africa surrounded by Zambia, Tanzania and Mozambique. Lakes account for 20% of the total area of 118,480km^2. With a total population of 13.2 million (according to the national census in 2008), the population density is 111 per square kilometer. The nation is divided into Northern, Central and Southern administrative regions.

Malawi is in the Pan-African tectonic zone, situated in the Nyasa Rift Valley in the southern tip of 6,000-kilometer-long East African Great Rift Valley tht traverses East Africa from the Red Sea. Its elevation ranges from 36 meters to 3,048 meters and most of the land is on plateaus at altitudes of 1,800 meters to 2,000 meters. The majority of the land is in the sub-tropical climate zone with the rainy season from December to March and the dry season from April to November. The precipitation in the rainy season ranges from 800mm to 2,000mm with the temprerature varying from 20°C to 37°C. There is very little precipitation in the dry season with the temperature ranging from 17°C to 27°C.

The project site is in a mountainous area in the northern part of the country, where the average annual temperature is 23°C with little month-by-month fluctuation and the average annual precipitation is 670mm that concentrates in the rainy season.

Situated in the Nyasa Rift Valley in East Africa’s Great Rift Valley, Malawi is prone to earthquakes. The earthquake in the Central region on March 10, 1989, killed three people and injured 60 people. Although not so frequently, earthquakes hit the country. However, the seismic acceleration around the project site is below 60 gal, which shows that the scale of seismicity is quite small.

After its independence in 1964, Malawi held the first multiparty general elections in May1994, which promoted liberalizataion through democratization and introduction of market economy. In May 2004, the third general elections were held and Bingu wa Mutharika of the United Democratic Front (UDF) was elected President. President Mutharika carried out administrative reform, which included the reduction of cabinet posts. He weighed practical experiences, appointing experienced figures in international organizations finance minister and other key ministerial posts. He also put importance on eradication of corruption and establishment of fiscal discipline, trying to emphasize the difference from the previous administration (former president Bakili Muluzi). President Mutharika who led the Democratic Progressive Party (DPP) was reelected in the presidential election in May 2009.

Per capita GNI was 230 USD in 2006. The primary industry accounts for 34%, secondary, 20%, and tertiary, 46%, of the national economy. The nation’s macroeconomic performance has been good for the last two years, with high economic growth rates at 8.5% in 2006 and 7.5% in 2007. The inflation rate was 7.9% in 2007. The basic annual interest rate is lowered to 15%. The good economic performance is a result of good agricultural production that accounts for 34% of the economy, particularly production of maize, the main food source of its people, thanks to good weather, as well as high buying price of tobacco, a major export of the country. However, agricultural production remains venerable, being affected by weather, and its economy faces the challenge of stable food supply. Its main crops and exports of tobacco, tea and sugar are also affected by international prices as well as transportation cost hikes because the nation is an inland country, leaving the nation's economy on a venerable footing.

(2) Background, History and Outline of the Project

The Government of Malawi formulated the Malawi Growth and Development Strategy (MGDS) in 2006 as a comprehensive national strategy for the following five years (from July 2006 to November 2010) aiming to ensure sustainable economic growth through infrastructure development as a step to poverty reduction. Comprising the "six key priority areas" and the "five main themes," the MGDS defines mid- to long-term achievement goals with the description of strategies for attaining the goals. The strategy for the road sector focuses on the establishment of safe, highly-efficient and economical transport services in key corridors that meet the country's current road transport needs.

Main Road No. 1 is a trunk route of the country with the total length of 1,108km traversing the country from Songwe bordereing Tanzamia to Marka bordering Mozambique. It not only plays a critical role for domestic distribution of goods but serves as an international artery to support the distribution from and to Tanzania, Mozambique, Zambia and South Africa.

The existing Rukuru Bridge is a one-lane bridge despite its location over Main Road No. 1, causing a bottleneck in traffic and distribution of goods. It is a temporary structure (a Bailey bridge), which has become decrepit after more than 30 years of use. As a result, the speed limit (10km/h) and load restriction (16.3 tons as design load) have been imposed. In addition, the South Rukuru River running beneath the Rukuru Bridge is joined by a tributary Lura River at a location 30 m upstream from the present bridge and the site around the bridge is filled with deposits of boulders and driftwood from the Lura River, severely damaging the bridge piers.

Against the background, the Government of Malawi requested the Government of Japan for grand aid for the construction of a new bridge to replace the existing Rukuru Bridge.

In response, JICA conducted a preliminary study from August 4 to September 7, 2008, to examine the request, target site, existing bridge and roads, and the plan to conduct IEE based on the JICA Guideline for Environmental and Social Considerations. The need and validity of the replacement of the Rukuru Bridge was confirmed.

(3) Outline of the Study Results and Contents of the Project

Based on the preliminary study, JICA dispatched a preparatory study team to Malawi from February 22 to April 16, 2009. The team examined and confirmed the bridge location and access roads, the profile plan of the bridge and access roads, provision of parking zones, width configuration, bridge type, alteration of the riverbed of the Lura River, procedures related to environmental and social considerations, natural environment, traffic volume, procurement of building materials, and operation, maintenance and management. Based on the study result, JICA examined the specifications of the bridge, access roads and bank protection and construction plan, estimated the project cost, and formulated a schematic design in Japan, before dispatching a team from August 6 to 15, 2009 to explain the schematic plan to the Government of Malawi. The team explained to the Malawi side about the master plan and discussed Malawi's responsibility with Malawi side and obtained its approval.

The project site where the bridge is planned to be constructed is chosen based on the following criteria: little impact of boulders and driftwood, as little relocation of private houses as possible, and low cost. For cost reduction, Malawi and Japanese standards are applied for the bridge type and specifications of access roads and bank protection. The basic design is formulated to have appropriate size and specifications for the bridge and bank protection to play their role they are expected to play. Economic efficiency and early completion are main criteria for deciding the construction method.

Taking the above issues into consideration, a final plan was proposed. The table below shows an outline of the plan.

Bridge type		2-span continuous PCT girder
Length		74 meters
Width		Roadway width 3.35m×2=6.7m, bicycle path width 0.3m×2=0.6m, sidewalk width 1.2m×2 =2.4m, total of 9.7m (effective width) (total width of 10.5m)
Bridge deck pavement		Asphalt pavement (roadway: 50mm)
Abutment type		A1 abutment: reverse T-type abutment (spread foundation) A2 abutment: reverse T-type abutment (spread foundation)
Pier type		Elliptical type (direct foundation)
Access road	Length	Right-side bank (Mzuzu side): Approx. 321m, left-side bank (Karonga side): Approx . 305m
	Width	Roadway width 3.35m×2=6.7m, bicycle path width 0.3m×2=0.6m, sidewalk width 1.2m×2 =2.4m, total of 9.7m (effective width) Protective shoulder 1.0m×2=2.0m, total of 11.7m (total width)
	Pavement	Asphalt pavement (surface: 50mm, upper layer roadbed: 150mm, under layer roadbed: 150mm)

(4) Project Schedule and Estimated Project Cost

In case the Project is implemented through Japan's Grant Aid, the duration of the project is estimated to require 25.5 months including the bidding process (6.0 months for detailed design and 19.5 months for construction).

The project cost required for fulfilling the undertakings by the Government of Malawi is estimated at 15,265 thousand MKW.

(5) Validation of the Project

The project is expected to have the following direct and indirect effects, benefiting 13.2 million Malawians directly and 56.68 million peoples of Tanzania and Zambia indirectly.

1) Direct effects

① The vehicle weight allowance increases significantly from the current design load of 16.3 tons to 43 tons, which accommodates an increase in traffic, an increase in large trucks, in particular.

② Currently, cars need to stop to let the oncoming car pass due to the narrow width. As the new bridge will have sufficient width, cars do not need to stop and the average traveling speed on the bridge will increase from the current approx. 10 km/h to 60 km/h.

③ Raising the height of the bridge and road by 2.5m, securing cross-sectional area of the river, and bank protection works mitigate flood damage caused to the bridge, access roads and neighboring area.

④ Building sidewalks on both sides separates the roadway and sidewalk, allowing smooth traffic flow and lowering the risk of accidents involving pedestrians.

2) Indirect effects

① Enhancing the load bearing ability of the bridge and ensuring stable transportation route stabilizes, normalizes and accelerates domestic distribution of goods, which will contribute to economic development of the northern Malawi that is relatively lagged behind the southern part and contribute to the development of market economy of the whole country.

② The bridge not only promotes distribution of goods but contributes to more active cultural exchange and exchange for tourism promotion and regional development as well as creation of stronger friendly tiles among southeastern African countries.

③ The construction of the parking zone enables vendors around the existing bridge to maintain their small-scale commercial activities.

The project is expected to bring about the enormous benefits as described above, while contributing to the improvement of people's livelihood. Thus, the validity of the Japanese grand aid project is confirmed. Because human resources and budget necessary for the operation, maintenance and management of the project are secured and there is no technical challenge, day-to-day maintenance and regular repair work can be performed. If the road maintenance of Main Road No. 1 where the bridge is built is performed appropriately, the project will bring about bigger effects.

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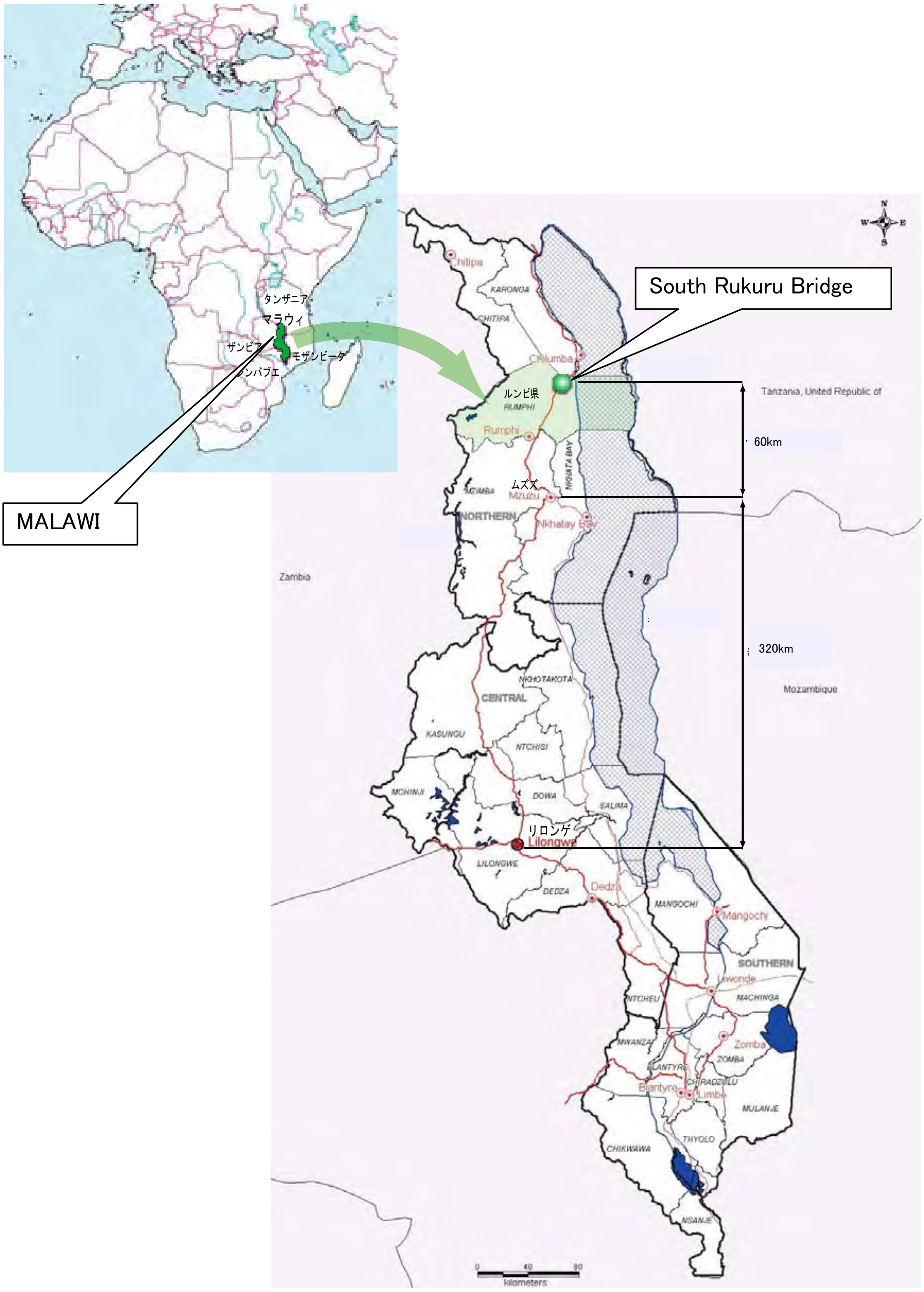
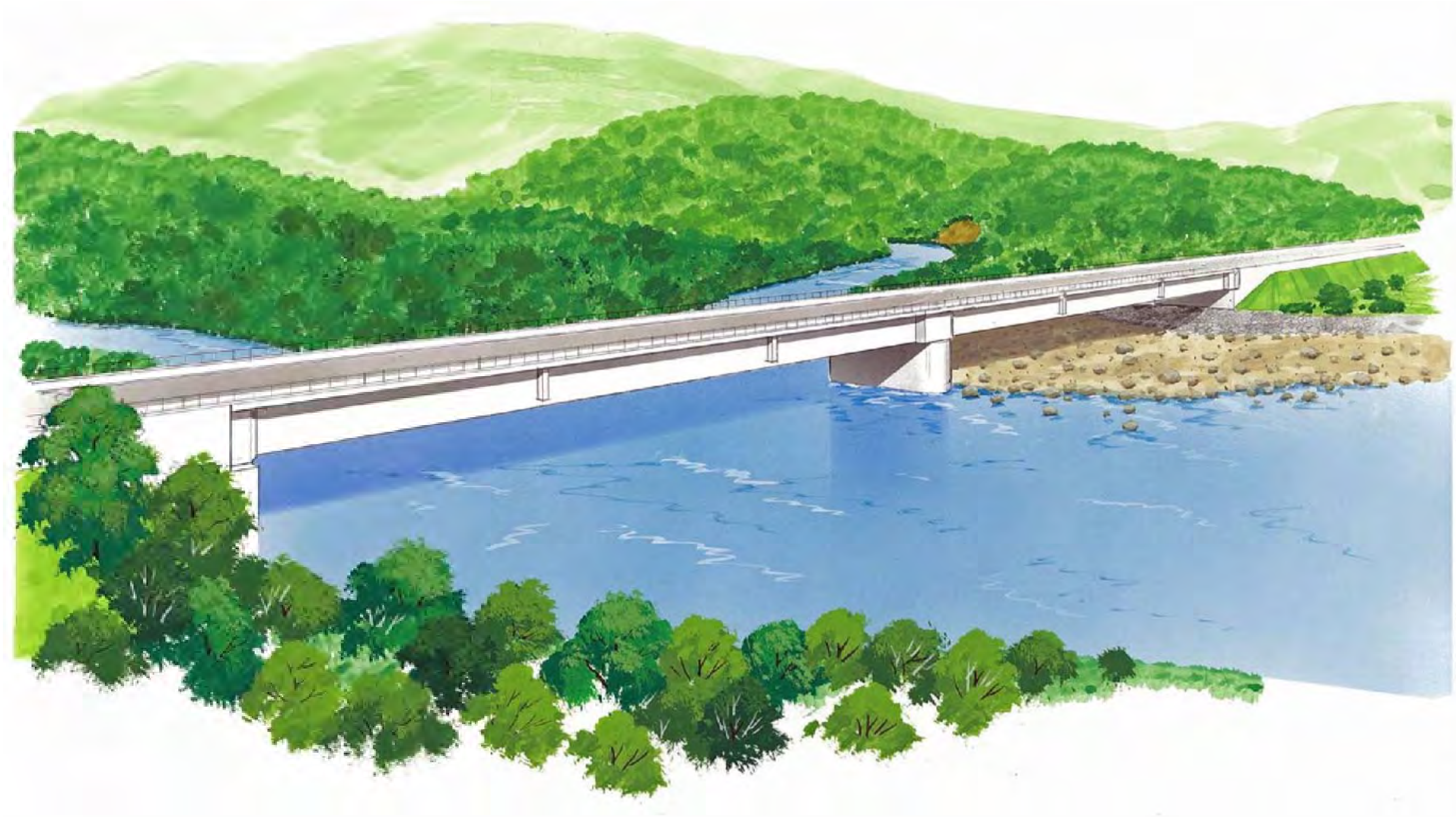


Location Map



Perspective View of South Rukuru Bridge

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Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
AfDB	African Development Bank
O/D	Outline Design Study
BS	British Standards
CBR	California Bearing Ratio
DEA	Department of Energy Affairs
EAD	Environmental Affairs Department
EIA	Environmental Impact Assessment
EMA	Environmental Management Act
E/N	Exchange of Notes
EU	European Union
HIV/AIDS	Human Immunodeficiency Virus/ Acquired Immunodeficiency Syndrome
IDA	International Development Association
GDP	Gross Domestic Product
GNI	Gross National Income
GL	Ground Level
HIPCs	Heavily Indebted Poor Countries
HS20-44	Design live load prescribed by AASHTO
IEE	Initial Environmental Evaluation
IMF	International Monetary Fund
JICA	Japan International Cooperation Agency
M/D	Minutes of Discussion
MDG s	Millenium Development Goals
MGDS	Malawi Growth and Development Strategy
MKW	Malawi Kwacha
MNREA	Ministry of Energy, Mines and Natural Resources
MOF	Ministry of Finance
MOMS	Ministry of Meteorological Service
MOTPI	Ministry of Transport and Public Infrastructure
NCE	National Council for the Environment
ODA	Official Development Assistance
PC	Prestressed Concrete
PSIP	Public Sector Investment Programme
RA	Roads Authority
RC	Reinforced Concrete
TCE	Technical Committee on the Environment
WB	World Bank

Chapter 1 Background of the Project

1-1 Background and Overview of Request for Grand Aid

The Republic of Malawi (hereinafter referred to as “Malawi”) is an inland nation situated in Southern Africa surrounded by Zambia, Tanzania and Mozambique. Lakes account for 20% of the total area of 118,480km^2. With a total population of 13.2 million (according to the national census in 2008), the population density is 111 per square kilometer. Its elevation ranges from 36 meters to 3,048 meters and most of the land is on plateaus at altitudes of 1,800 meters to 2,000 meters. The majority of the land is in the sub-tropical climate zone with the rainy season from December to March and the dry season from April to November. The precipitation in the rainy season ranges from 800mm to 2,000mm with the temperature varying from 20°C to 37°C. There is very little precipitation in the dry season with the temperature ranging from 17°C to 27°C. The project site is in a mountainous area in the northern part of the country, where the average annual temperature is 23°C with little month-by-month fluctuation and the average annual precipitation is 670mm that concentrates in the rainy season.

The Government of Malawi formulated the Malawi Growth and Development Strategy (MGDS) in 2006 as a comprehensive national strategy for the following five years (from July 2006 to November 2010) aiming to ensure sustainable economic growth through infrastructure development as a step to poverty reduction. Comprising the “six key priority areas” and the “five main themes,” the MGDS defines mid- to long-term achievement goals with the description of strategies for attaining the goals. The strategy for the road sector focuses on the establishment of safe, highly-efficient and economical transport services in key corridors that meet the country’s current road transport needs.

Main Road No. 1 is a trunk route of the country with the total length of 1,108km traversing the country from Songwe bordereing Tanzamia to Marka bordering Mozambique. It not only plays a critical role for domestic distribution of goods but serves as an international artery to support the distribution from and to Tanzania, Mozambique, Zambia and South Africa. However, the existing Rukuru Bridge over the national highway (The new bridge shall be referred to as “South Rukuru Bridge.”) has the following problems and urgent replacement is regarded as a priority issue of the country.

① The existing Rukuru Bridge is a one-lane bridge despite its location over Main Road No. 1, causing a bottleneck in traffic and distribution of goods.

② It is a temporary structure (a Bailey bridge), which has become decrepit after more than 30 years of use. As a result, the speed limit (10km/h) and load restriction (16.3 tons as design load) have been imposed.

③ The South Rukuru River running beneath the Rukuru Bridge is joined by a tributary Lura River at a location 30 m upstream from the present bridge and the site around the bridge is filled with deposits of boulders and driftwood from the Lura River, severely damaging the bridge piers.

④ Because the South Rukuru River and the Lura River meet, serious floods are caused in the rainy season every year, which hinders smooth flow of traffic.

Against the background, the Government of Malawi requested the Government of Japan for grand aid for the construction of a new bridge to replace the existing Rukuru Bridge. In response, JICA conducted a preliminary study from August 4 to September 7, 2008, to examine the request, target site, existing bridge and roads, and the plan to conduct IEE based on the JICA Guideline for Environmental and Social Considerations. The need and validity of the replacement of the Rukuru Bridge was confirmed.

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1-2 Natural Environment

1-2-1 Weather and Hydrological Conditions

(1) Weather Survey

The Ministry of Meteorological Service (MOMS) has compiled meteorological information and the data is gathered in Blantyre. We collected from MOMS the records in Bolero (48km), the observation point nearest to the bridge site, and the Mzuzu observation station (78km).

Table 1-2-1 Weather Survey Items and Acquired Information

Survey Item	Details	Observation Station/Duration	Source
Temperature	Monthly (high/low)	Bolero, Mzuzu 1998-2008	MOMS
Rainfall	Daily	Bolero, Mzuzu 1998-2008	MOMS
Wind Speed	Monthly average	Bolero 1997-2007	MOMS
Natural Disaster	Flood level, flooding	Recent floods	Interview
Humidity	Monthly average	Bolero 1993-2008	MOMS

1) Temperature

The monthly mean temperature in Bolero, the observation point nearest to the bridge site, drops to the lowest level of about 17°C in July and rises to the highest level of 26°C in October. The monthly maximum temperature varies in the range from 25 to 32°C throughout the year, peaking in November to 31.9°C in the 10 year average. The minimum temperature drops below 10°C in June and July, although it is about 16°C in the 10 year average. The annual range of temperature is about 13°C.

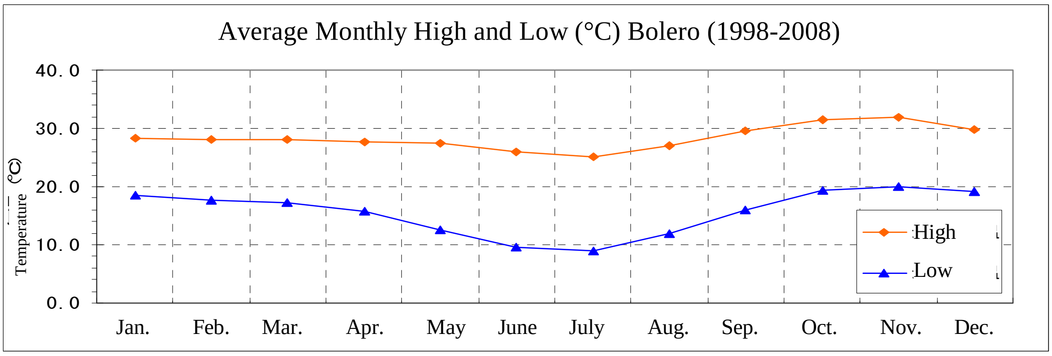


Fig.1-2-1 Yearly Temperature Variation (Bolero Observation Station)

(2) Hydrological Survey

1) Rainfall

i) Monthly Rainfall

The annual rainfall at the project location is about 670 mm in the 5 year average, showing a wide yearly variations ranging from 400 mm to 900 mm. Generally in Malawi, the dry season extends from April to November, and the rainy season from December to April. In Bolero, rainfall decreases gradually in April and there is practically no rain from May to September. Rainfall increases in the period from October to December.

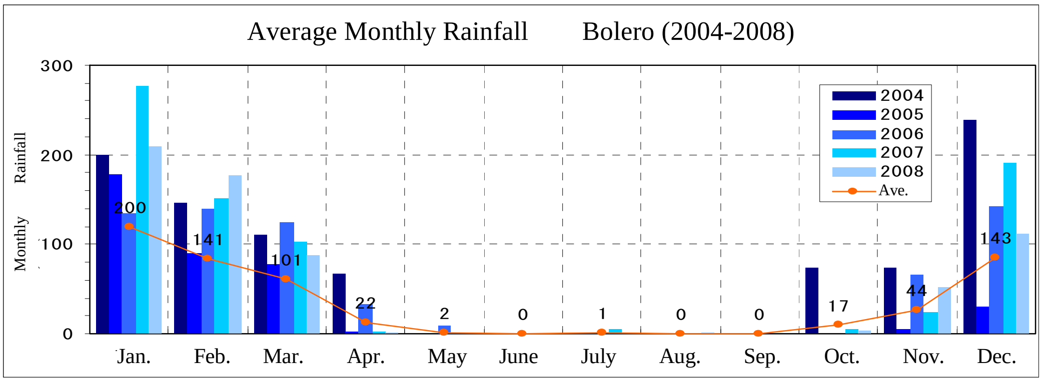


Fig.1-2-2 Monthly Rainfall (Bolero Observation Station)

ii) Record High Daily Rainfall

The country does not have much rainfall: The average monthly rainfall is below 10mm during the dry season from April to November, during which it is close to zero from May to September, while the average monthly rainfall during the rainy season from December to March is approximately 40mm. The record high daily rainfall over the last five years is 65.9mm in January 2006.

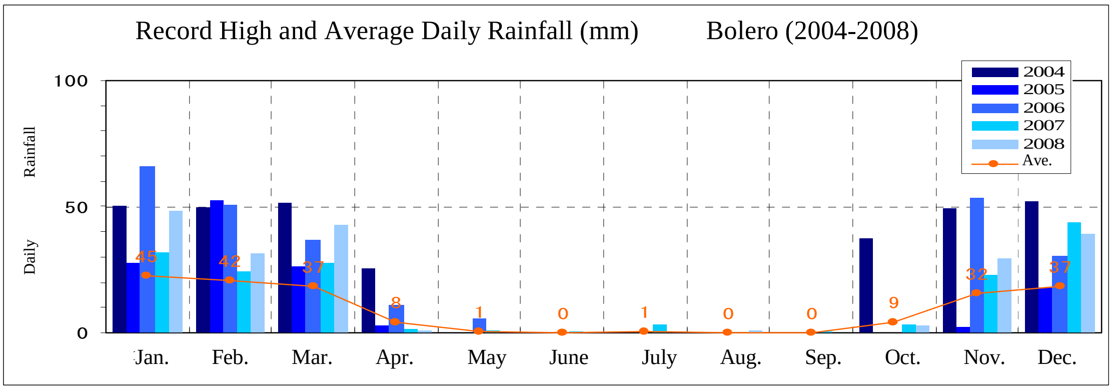


Fig.1-2-3 Record High Daily Rainfall (Bolero Observation Station)

2) Flow Rate

Flow rate data obtained at the Phwezi observation station 20km upstream of the South Rukuru River from the location of the new bridge is available. We sorted out the data during the five years from 1979 to 1983 when no data is missing. The water flow begins to increase in December when the rainy season starts and between January and mid-May, with a significant increase in March and it decreases gradually from mid-May after the beginning of the dry season until late November. The flow rate is significantly low for six months from June to November. There is remarkable difference of the flow rate between the rainy season and dry season. The design flow rate at the location of the bridge will be the total of the flow rate at the Phwezi observation station and that of the South Rukuru

River and its tributary of the Lura River.

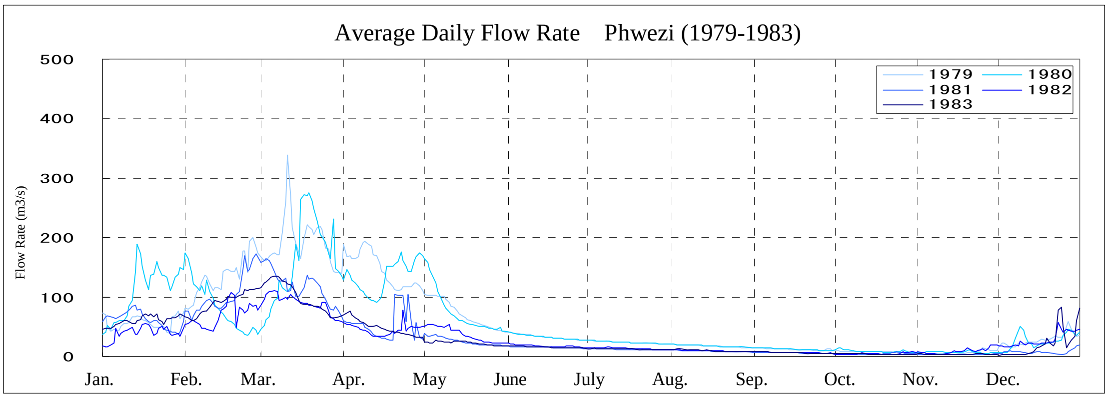


Fig.1-2-4 Average Daily Flow Rate (Phwezi)

3) Estimation of Design Flood Discharge

As for the design flood discharge, water level is calculated in consideration of the flood level and river channel conditions based on the current channel cross section in consideration of the boulder deposits to estimate the flow capacity.

Based on the probability estimation of the flow rate data obtained at the Phwezi observation station approx. 20km upstream from the location of the new bridge, the rate at the probability of 1/50 is obtained. At the same time, the flood flow rate of the residual basin areas of the South Rukuru River between the observation station and the bridge site and of the tributary Lura River is obtained based on the rainfall intensity, runoff coefficient and basin area obtained from the daily rainfall at the probability of 1/50 to estimate the flood level. The obtained values are used to estimate the design flood discharge at the bridge. Then the river channels of the upstream and downstream of the bridge and the confluence of tributaries are taken into consideration in designing the channel cross section at the bridge point and the water level at the design flood discharge is calculated to estimate the design high water level for the design flow rate. Because the bathymetry of the channel cross section is yet to be carried out, the design flood discharge and design high water level are estimated based on the result of the voluntary survey in December 2008.

4) Calculation Result

① Flow capacity of current river cross section

The rough river cross section at the existing bridge point is obtained from the river surveying last year and field survey in the past to estimate the current flow capacity at floods. The flow level at floods is estimated to be 858.8m= 858.0m (bridge deck value we learned in the interview) + 0.8m. The average river gradient of 1/150 and roughness coefficient of 0.045 are used to calculate the water level. From the calculation, we obtained the current flow capacity: Q=1,171m^3/s.

② Flow capacity of design cross section

The boulders and driftwood on the left-side bank at the existing bridge point are subtracted from the flow cross section to estimate the design cross section that is almost equal to the channel cross section. Plan 3 was used as bridge type (2-span PC bridge with one pier in the center) and the confluence of the Lura River was taken into consideration. The flow capacity at the water level, 857.0m, which is 1.0m below the current bridge deck (858.0m) is estimated: Qdesign＝1,180m^3/s.

The allowance height under the Japanese government ordinance for structural standards for river management facilities is 1.0m for the design flow of 500m^3/s to 2,000m^3/s. When the design high water level is 857.0m, the cross section has to be secured by removing soil and stone in the drought season every year.

③ Design flood discharge

The flood discharge estimated based on the current flow capacity is approx. 1,200m3/s at the peak. According to the probability estimation of the annual maximum of daily mean flow based on the data for the South Rukuru River obtained from the preliminary study, the maximum flow is calculated to be 400 m^3/s at the probability of 1/50. The Lura River has the width of about 40 m and the slope of 1/50. Assuming the water depth of 1.5 m and the roughness coefficient of 0.035, the flow volume corresponding to the flow capacity is Q = 303 m^3/s. Because the daily rainfall at the 1/50 probability is 90.6 mm/h, the rational formula gives 487 m^3/s from the basin area Alura = 153 km^2, f = 0.7, and r = 16.4 mm/h. The flood discharge is estimated to be between 300 and 500m3/s based on the flow capacity and estimated flow volume.

Similarly, for the residual basin area of the South Rukuru River, the rational formula gives 363 m^3/s from the basin area Arukuru = 130 km^2, f = 0.7, and r = 14.4 mm/h. Assuming that the South Rukuru River and the Lura River reach the peak simultaneously at confluence, we obtain:

Design Flood Flow = 400 + (303)487 + 363 = 1,066 to 1,250m^3/s.

The peak flow values have been calculated somewhat exaggerated, because the flow volume values in the residual basin areas of the tributary Lura River and the South Rukuru River are the values calculated assuming no retention and this calculation is usually applied to the case with the basin area of 100 km^2 or less.

Considering this fact, it may be assumed that the design flood discharge at the bridge location is 1,200 m^3/s.

1-2-2 Topographical and Geological Surveys

(1) Topography

Malawi is in the Pan-African tectonic zone, situated in the Nyasa Rift Valley in the southern tip of 6,000-kilometer-long East African Great Rift Valley tht traverses East Africa from the Red Sea. Its elevation ranges from 36 meters to 3,048 meters and most of the land is on plateaus at altitudes of 1,800 meters to 2,000 meters.

The project site is over Main Road No. 1 , a 1,108-kilometer-long trunk road traversing the country from Songwe bordereing Tanzamia to Marka bordering Mozambique. The existing Rukuru Bridge is built in a mountainous area approx. 860 meters above sea level approx. 500 kilometers north of the national capital of Lilongwe, about 30 meters downstream of the confluence point of the South Rukuru and Lura Rivers. Main Road No. 1 runs close to the mountainside (approx. 60°) before the bridge (Mzuzu side) on the right bank side. It is flat to the point where small stores are located on the left bank side, from which the South Rukuru River runs and gentle slope goes all the way to the river bank. Flat field spreads on the right side and the Lura River runs along the mountainside (30 to 45°) on the left side of Main Road No. 1 from the existing Rukuru Bridge (Karonga side). A topographical map of the area is shown in the following page.

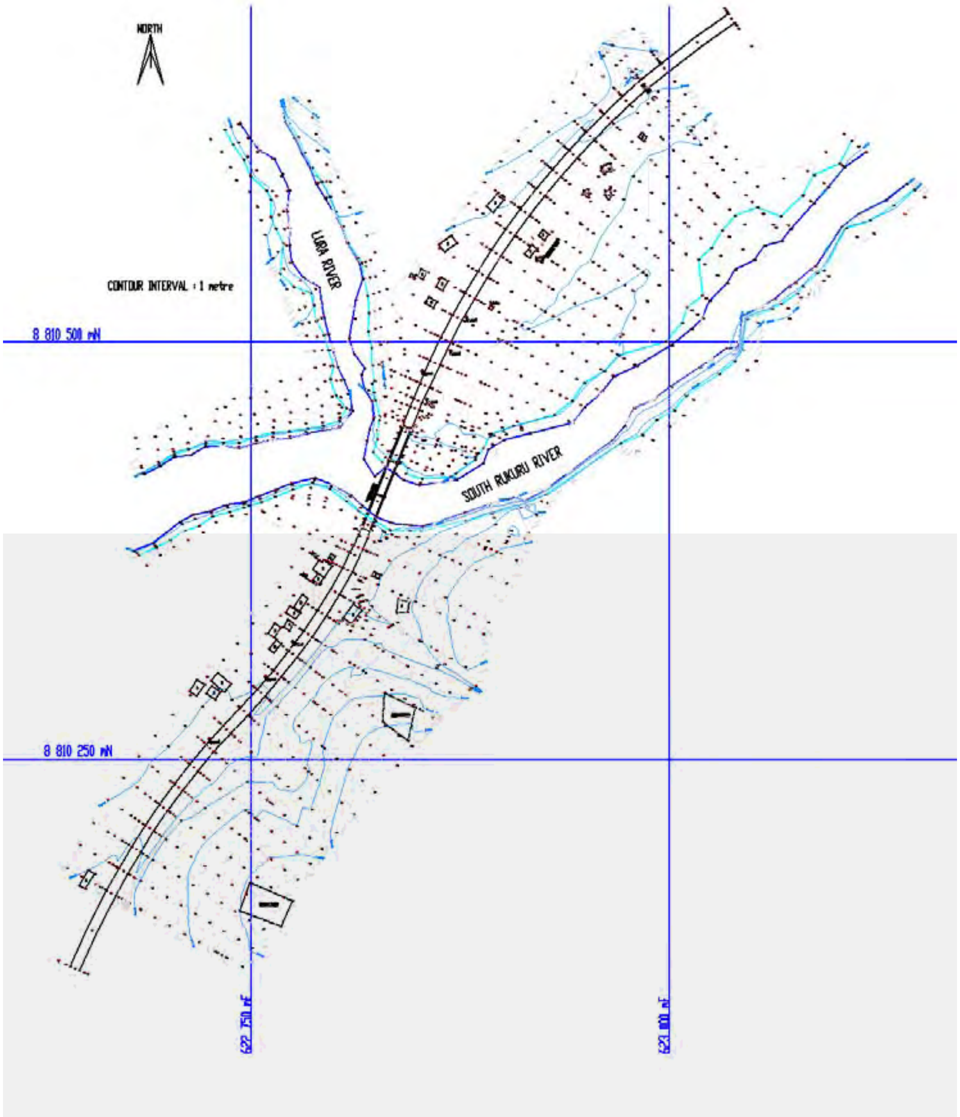


Fig.1-2-5 Plane Survey

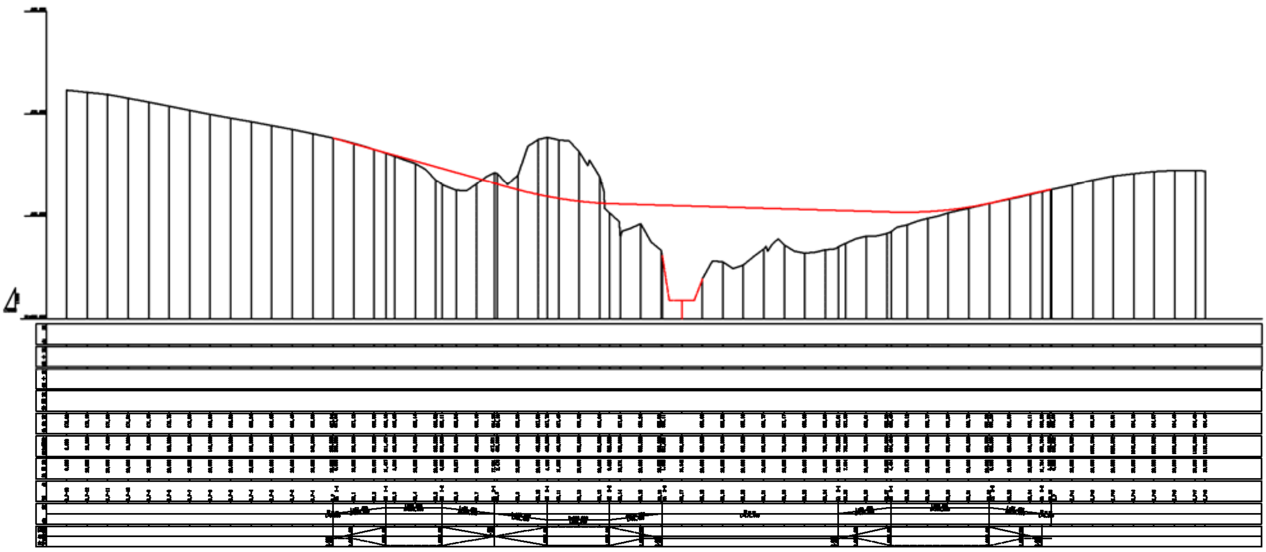
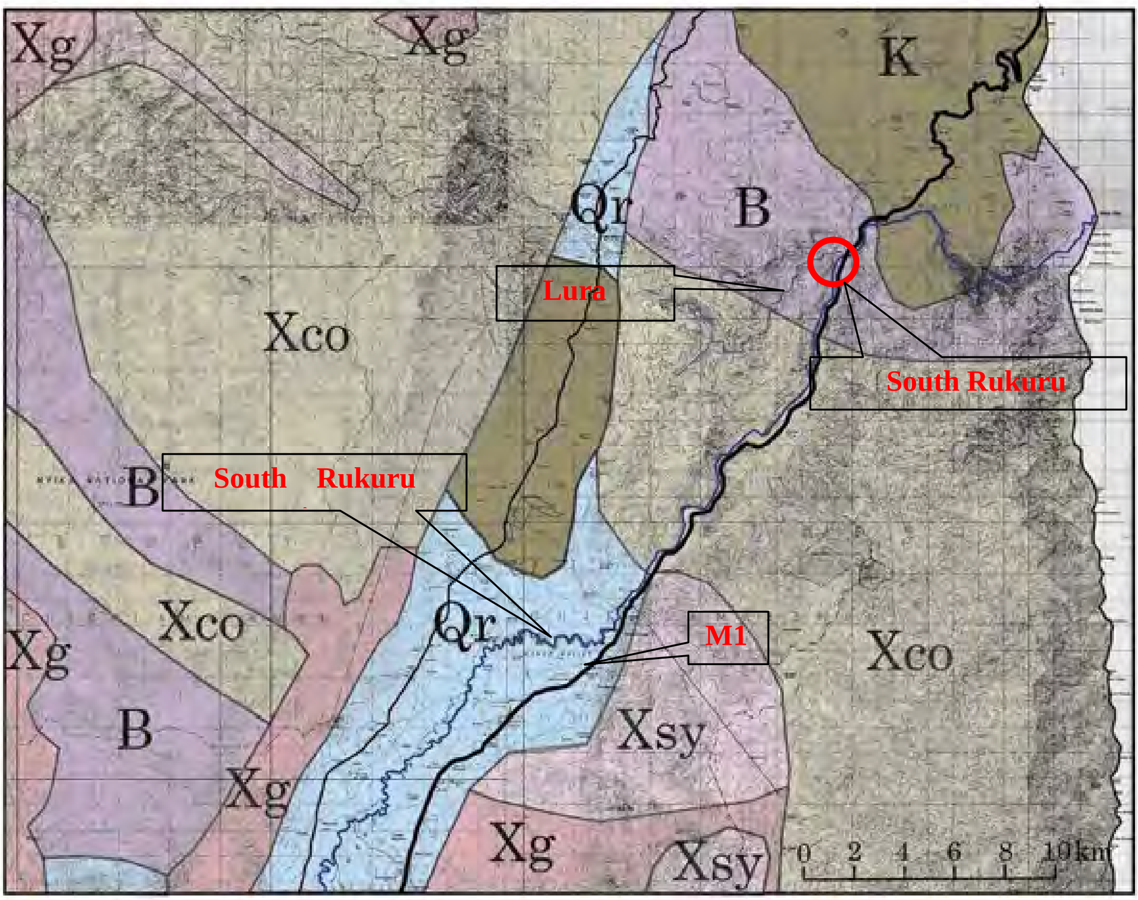


Fig.1-2-6 Profile Leveling

(2) Geology

According to the geological map of Rumphi District, geological conditions around the project site are shown in Figure 1-2-7.



Sedimentary rock (from tertiary to modern periods)
Qr: sediments of residual soil in diluvium and alluvial epochs
Sedimentary rock (from Permian to Triassic periods)
K: Karroo System, gravel, sandstone, mudstone, carbonaceous shale,
Metamorphic rock (lower Precambrian to lower Paleozoic eras)
B: biotite, hornblende-containing gneiss, anatexite
Xco: cordierite, cordierite gneiss
Igneous rock (Mesozoic period)
Xsy: syenitic and perthic complex in substratum
Xg: granitic body in substratum

Fig.1-2-7 Geological Map around Project Site

The geological map shows that the area lies on gneiss (B) in the lower Paleozoic era and the sedimentary rocks from Permian to Triassic periods distribute on the northeastern side of the gneiss. The sedimentary rocks from Permian to Triassic periods distribute approx. 800 north of the planned bridge site toward northeast, where mining operation is conducted in the Chiweta coal mine.

The drilling survey result shows that the strata formed from Precambrian to Paleozoic eras around the project site comprise granitic gneiss and crystalline schist. The former features pink orthoclase and contains black hornblende. It is very hard and highly resistant to weathering. Crystalline schist is sericite schist with local distribution of quarts schist, forming extremely hard lithofacies. Geological cross section is shown in the following page.

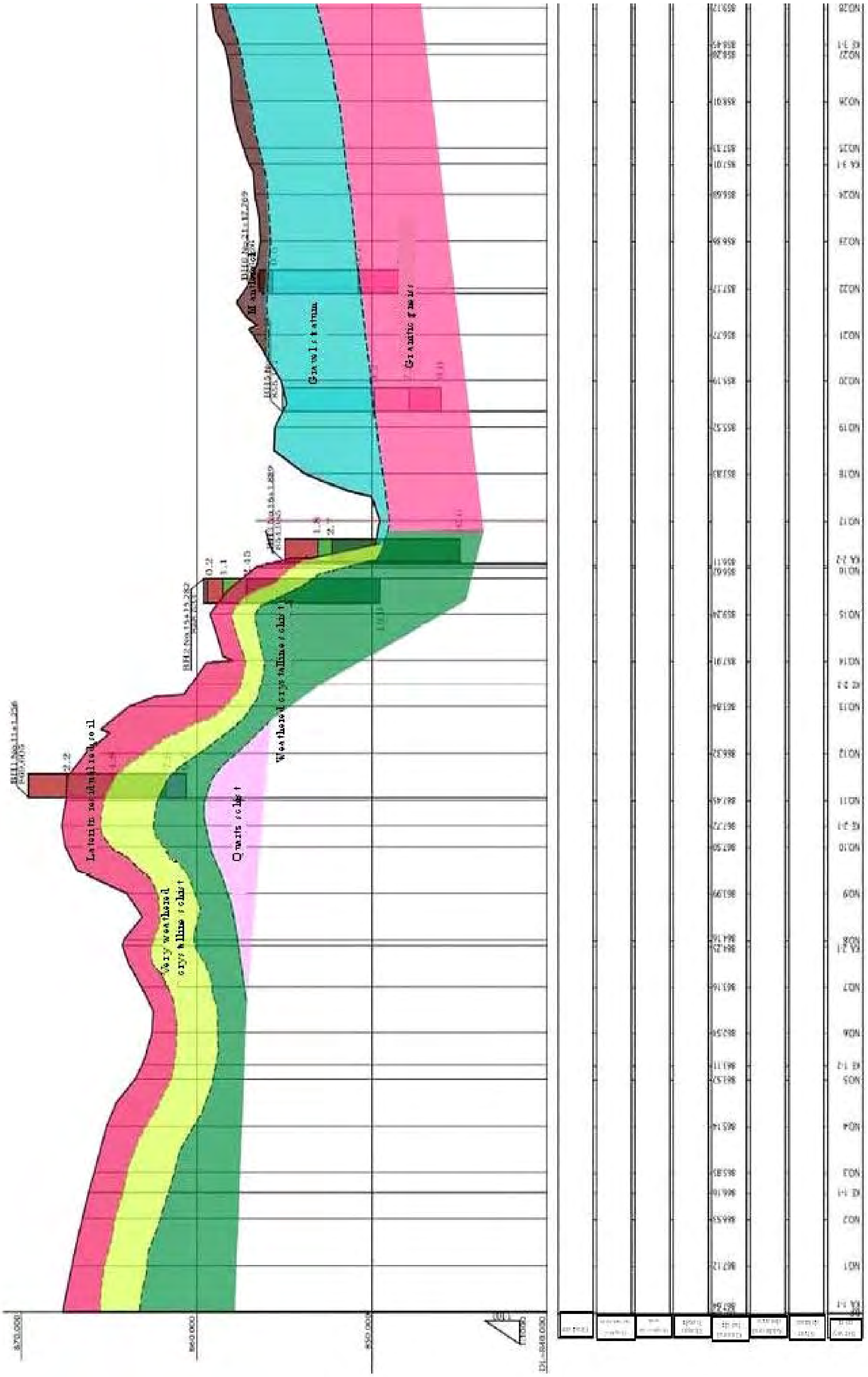


Fig.1-2-8 Geological Cross Section

1-2-3 Seismic Survey

Figure 1-2-9 shows seismic distribution in Malawi between 1901 and 2007.

Figure 1-2-10 shows acceleration distribution for the South Rukuru Bridge of earthquakes that occurred in the country.

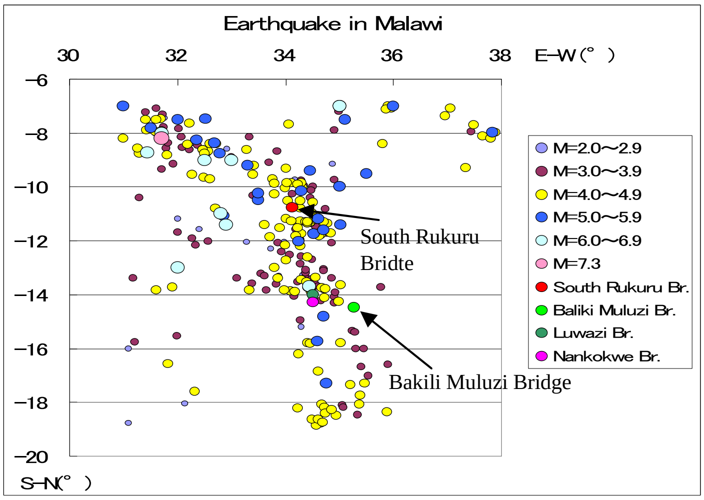


Fig.1-2-9 Seismic Distribution in Malawi

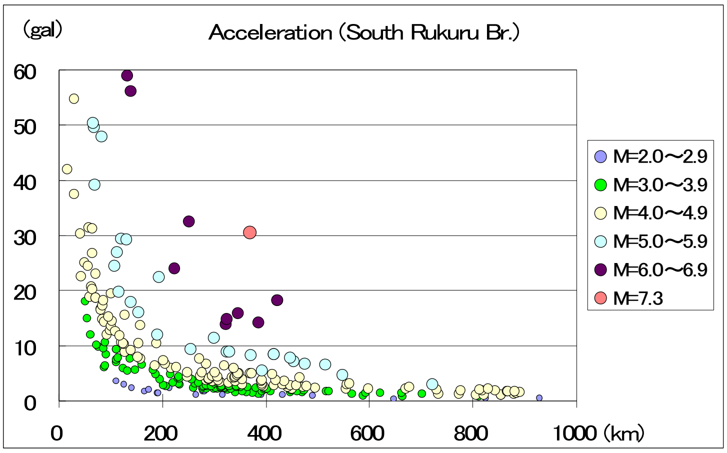


Fig.1-2-10 Acceleration Distribution for South Rukuru Bridge

Figures 1-2-11 to 1-2-13 show acceleration distribution for Bakili Muluzi Bridge (Mangochi bridge), Luwazi Bridge and Nankokwe Bridge that were all built in Japan's grant aid projects.

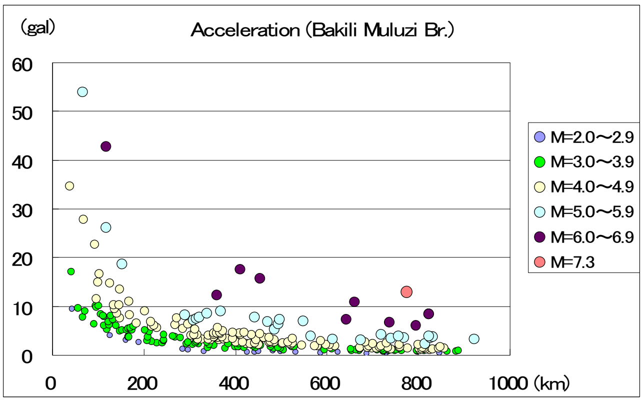


Fig.1-2-11 Acceleration Distribution for Bakili Muluzi Bridge (Mangochi bridge)

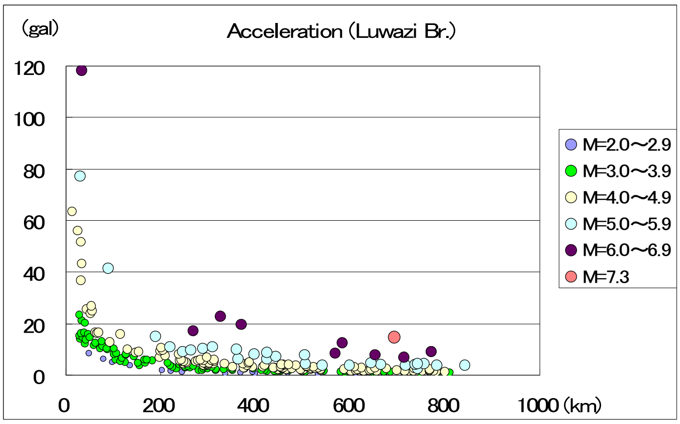


Fig.1-2-12 Acceleration Distribution for Luwazi Bridge

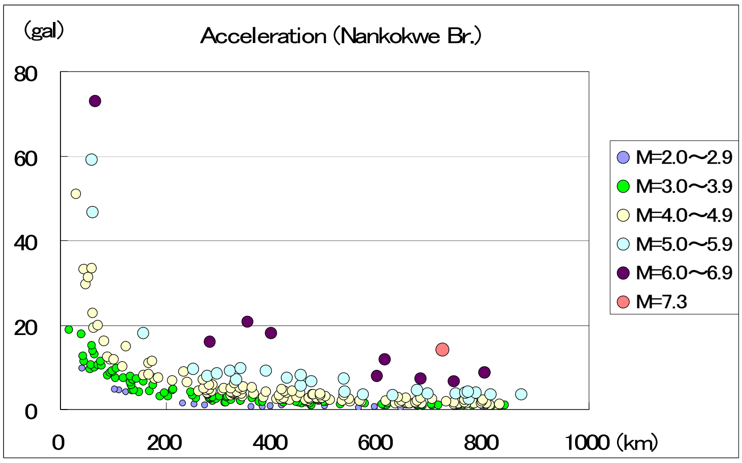


Fig.1-2-13 Acceleration Distribution for Nankokwe Bridge

1-2-4 Environmental and Social Considerations

(1) Environmental Category

This Project involves a replacement of the existing bridge, which poses no serious environmental and social impact, and the inhabitants around the project site agree to the construction of a new bride, in essence; however, the Initial Environmental Examination (IEE) conducted as a part of the preliminary study determined the project as Environmental Category "B", considering the consequences on the livelihood in the vicinity, the generation of muddy waters and wastes in the course of the construction works, and the potential adverse impacts on the sanitary conditions and wildlife. In this study, the categorization was reassessed based on JICA's "Guidelines for Environmental and Social Considerations April 2004", by conducting field surveys. The purpose was to scrutinize the impacts on the livelihood of inhabitants and further examine about the land acquisition now that the location of the new bridge is finalized. A downstream area from the existing bridge, where there is no permanent inhabitant, has been chosen as the construction site. It is deemed that the environmental and social impacts that arise out of the actual construction will not exceed the level ascertained in the preliminary study. Thus, the study team reached a conclusion that Category "B", the classification made in the preliminary study, should appropriately remain unchanged.

(2) Procedures for Environmental Impact Assessment (EIA) in Malawi

In Malawi, the Section 5 of the Environmental Management Act of 1996 stipulates that a designated project cannot obtain the permission for project implementation from competent authorities until an

EIA is conducted and the approval of the Director of Environmental Affairs is obtained. The designated projects are listed in the Guidelines for Environmental Impact Assessment prepared by Environmental Affairs Department (EAD) in 1997. Within the transport sector, projects for new construction and expansion of trunk roads and local roads are classified as designated projects. However, it is not specified clearly whether or not a project involving a bridge alone is a designated project.

Regarding this Project for the replacement of South Rukuru Bridge, the Road Authority (RA) as the project implementing body has submitted a project brief to EAD at the time of the JICA's preliminary study, and the screening by the EAD staff has concluded that an EIA is needed. The current EIA scheme in Malawi is based on the project assessment in which environmental impacts are assessed after the specifics of the project are defined to a reasonable extent, and the EIA report needs to contain concrete information such as the plans of constructed facilities, construction work schedules, estimated cost, plans for improving the areas around the site, and the number of workers. Therefore, an EIA has not been approved at the time of beginning this assistance preparatory study (March 2009).

Regarding the procedures for the EIA concerning the South Rukuru Bridge replacement project, a local EIA consultant selected by RA (Henderson & Partners) prepared a Draft EIA Report (First Edition) based on the supply of concrete information including sketch drawings, outline work plans, and waste treatment methods from JICA and submitted it to RA on April 1, 2009.

The potential serious environmental impacts identified in the Draft EIA Report (First Edition) include the deterioration of hygiene condition and increase in sexually transmitted diseases resulting from the inflow of construction workers, the increase in disease-carrying insects resulting from the improper management of borrowing pits, and the impact on the hydropower generation project in the downstream area. Mitigation measures listed in the report are the provision of water supply and toilets for the exclusive use by construction workers, the advance explanation of the details and impacts of construction to inhabitants, the ensuring of construction waste treatment in approved treatment sites, the environmental monitoring of work sites, and the refilling and planting of the sites after completion of work as part of the environmental management plan and the environmental monitoring plan. Because these plans have been developed before the determination of the detailed specifics of the construction work, they include actions that are unnecessary in actual work or impractical due to the actual condition of the site. However, the consultants performing detailed design and work supervision and construction contractors must sufficiently respect the contents of these plans.

While the Draft EIA Report was submitted via RA to EAD in June, the process leasing to the approval of the EIA Report requires the discussion at a monthly meeting of the Technical Committee on the Environment (TCE) and a National Council for the Environment (NCE) meeting held at 3-month intervals. If it is to be approved by August, it must be discussed at the NCE meeting between June and July. Because this Project is an issue of national importance and the expected environmental impacts are mild, the responsible person at EAD expects approval by August provided that the Draft EIA Report contains all necessary information.

In actuality, the TCE did take place on July 3, and a commitment to hold an NCE in August was obtained from the relevant organization of Malawi, as compiled in the Record of Discussions in the DBD study. Nevertheless, it was later confirmed that the NCE would be held no earlier than September 30. As a provisional measure, the study team obtained a letter signed by the Director of Environmental Affairs of Malawi, promising that a certificate be issued as soon as the NCE is over. On September 30, the NCE concerning the project was held accordingly, and an EIA was obtained on October 16.

A flow chart showing the procedure for EIA approval is provided on the next page.

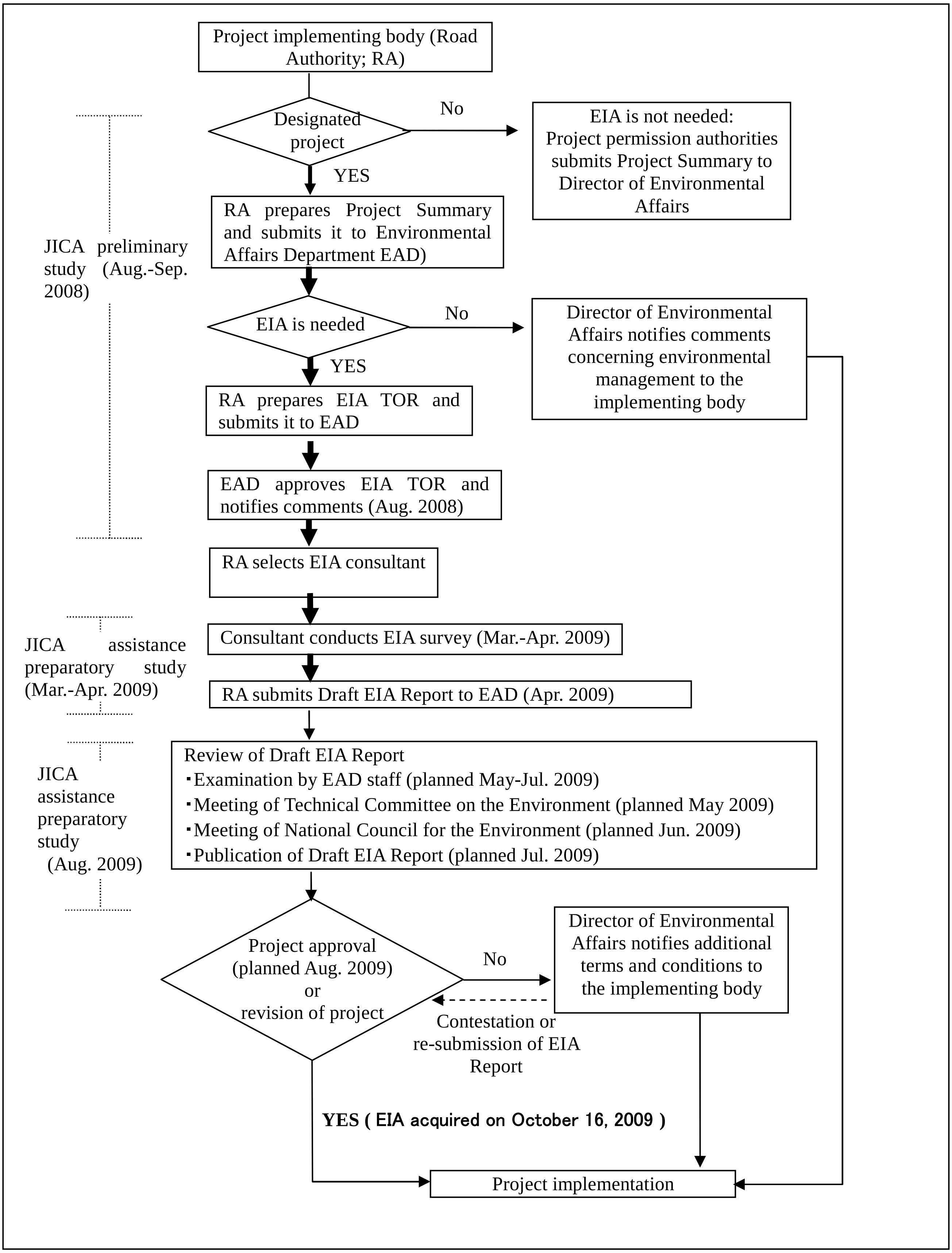


Fig. 1-2-14 EIA Flow Chart

(3) Major Environmental and Social Impacts and Corresponding Mitigation Measures

1) Relocation of inhabitants and acquisition of land

Lands are Customary Land and road land, and residents are not compensated because they don't have the ownership. Houses and fruit trees are the subject of compensation. Moreover, in public road law, 30m of right and left from the central line of a trunk road is Right of Way. Therefore, there is originally no necessity for compensation about the housing of this range. However, ERA is planning to pay the compensation to the objects which are targeted for the move because of the purpose of smooth implementation for the project.

The new bridge is planned at the location 16-19 m downstream over the South Rukuru River. In this case, the following four buildings need to be demolished for the sake of securing land for road construction at the time of the preparatory study (March 2009).

On the right bank:

① A store with no commercial operation or inhabitants (the owner lives in a different town)

② A rented house with no inhabitants (the owner lives in Mzuzu)

On the left bank:

① A ruined house formerly rented to miners (the owner lives in the neighborhood)

② A ruined house (the owner lives in a different town).

The four houses to be demolished had no inhabitants presenting March, 2009, and the number of inhabitants to be relocated is zero. The stores currently operating near the ends of the upstream area from the bridge need not be demolished within the expected scope of bridge replacement work.

The Land Office of Rhumphi Distict will take charge of the negotiation with inhabitants and the formation of agreement regarding land acquisition. The stakeholder meeting held in the preliminary study confirmed the basic consensus of the inhabitants supporting the bridge replacement project. In addition, the Land Office has completed the asset assessment of the houses, farmlands, trees, etc. around the existing bridge. Individual negotiations with the owners of properties will begin after the finalization of the land acquisition lands for roads and construction yards. The procedure for land acquisition will require at least two months.

Since the residents don't have the ownership, the substitute lands are offered as the compensation of land acquisition.And properties including a house, harvest expenses, livelihood recovery, move, the charge of troublesome, etc. are served as compensation in money. Such compensation expense is assessed based on the standard price which Ministry of Land and Housing and Physical Planning (MoLH&PP) defines. According to Rumphi District Land Office which takes charge of negotiations on compensation, the amount of presentation does not become a problem in Malawi.

2) Impacts on stalls and vendors operating around the existing bridge

There are five simply-built stores (including one closed) on the right bank and two on the left bank dealing in foods and commodities. Most of these stores are owned by the inhabitants of hilly areas at a distant from the road and the merchants living in Mzuzu. Except for one store (on the upstream side of right bank), these have no inhabitants at night. In addition, there are street venders selling local bananas and vegetables stalls offering small fish and meat dishes to the people in vehicles stopping at the ends of Rukuru Bridge, forming a small market around Rukuru Bridge. About 1/3 of the vehicles that stop to let opposite traffic pass are using this market in one form or another. According to the EIA survey, the annual sales of these venders amount to about MKW 10,000. The commercial activities in this form are providing important means for living to the inhabitants around Rukuru Bridge in the poorest region (with per-capita annual income below MKW 10,029).

The completion of the new bridge will reduce the number of vehicles stopping at the ends of the bridge, and the livelihood of the stores and farm product vendors operating around the bridge will be affected adversely. According to the interviews with the owners of the stores around the bridge, they know about the replacement of South Rukuru Bridge, and all of them wish to continue store operation after the replacement of the bridge. To mitigate the impact of new bridge construction on local inhabitants in this form, this Project plans to provide new parking zones at the both ends of the bridge. When accessed from the Lake Malawi side, Rukuru Bridge is located at the top of a steep hill as long as over 10 km. It is therefore expected that the new parking zone will be used effectively by drivers for the purposes of taking rests and checking vehicle conditions.

3) Impacts on wildlife

Most of the lands around Rukuru Bridge are used for cultivation and housing, and natural vegetation remains only in a part of the area on the right bank downstream from the bridge. The preliminary study confirmed the presence of two trees specified for protection as useful tree species under the Forest Rules of 2001. However, cutting of these trees for public work purposes does not involve legal problems. In addition, trees should be planted after felling of the protection trees.

Because the Lura River is a river where mudflows occur frequently after rainfall, the area around the construction site is not likely to harbor fish species that may be endangered significantly by the muddy water resulting from construction work. Fufu Fall and Wangwe Fall located about 3 km and 5 km downstream from South Rukuru Bridge block fish from running up the stream; therefore, there is no fish species running up the Rukuru River from Lake Malawi to the construction site for spawning or other purposes. Therefore, although the South Rukuru Bridge replacement project will cause significant alteration of river conditions around the project site, there will be no serious impacts on fish, and the recovery of the ecosystem is expected to take place early after the completion of work.

(4) Environment Monitoring Plan

The Draft EIA report cites the following items as subjects of monitoring in the environment monitoring plan. The specific methods of monitoring these items should be thoroughly discussed among the RA, construction supervising consultant, and contractors, prior to the commencement of the works.

- River water contamination resulting from improper waste disposal or wastewater treatment
- Loss of habitats due to disturbances to the ecosystem
- Depletion of precious and protected plant species
- Dust generated by vehicle traffic and civil engineering
- Noise arising out of heavy machinery operations
- Occupational hazards during the construction works
- Sanitary conditions during the construction works
- Increase in sexually transmitted diseases
- Loss of the means of earning of the inhabitants
- Involuntary relocation of houses
- Alteration to river flow conditions
- Change in land use

Chapter 2 Contents of the Project

2-1 Basic Concept of the Project

2-1-1 Overall Goals and Project Goals

2-1-1-1 Malawi Growth and Development Strategy

(1) Outline of the MGDS

The government of the Republic of Malawi (hereinafter referred to as Malawi) formulated the Malawi Growth and Development Strategy (MGDS) in 2006 as a comprehensive strategy for the country for the next five years (from July 2006 to November 2010) aiming at the creation of wealth through sustainable economic growth and infrastructure development as a step to poverty reduction. Comprising the "six key priority areas" and the "five main themes," the MGDS defines medium to long-term achievement goals with the description of strategies for attaining the goals.

《Six Key Priority Areas of MGDS》

① Agriculture and Food Security
② Irrigation and Water Development
③ Transport Infrastructure
④ Energy Generation and Supply
⑤ Integrated Rural Development
⑥ Prevention and Management of Nutrition Disorders, HIV and AIDS

《Five Main Themes of MGDS》

① Sustainable Economic Growth
② Social Protection
③ Social Development
④ Infrastructure Development
⑤ Improving Governance

The MGDS aims to achieve the annual GDP growth rate of at least 6.0% towards the achievement of poverty reduction and other goals. It emphasizes that the private sector should actively engage in investment and actions for socioeconomic development, as well as that the public sector and the private sector should work together to realize infrastructure-related investment and provide an institutional framework as a prerequisite condition for the promotion of appropriate environmental improvement. The main components of the strategy for the transport sector in the MGDS vision are as follows.

(2) Road Transport Sector

The strategies focus on ensuring availability of adequate, safe, reliable, highly-efficient and economical transport services in key corridors that meet the country's current road transport needs.

- Improving road network: By 2011, 71% of the road network will be in "good" condition and 18% in "fair" condition with only 11% in "poor" condition.
- Providing adequate network of roads through rehabilitation and upgrading of all-weather roads.
- Undertaking routine road maintenance to clear backlog based on appropriate standards.
- Building the capacity of local private sector to construct high quality roads.
- Replacing timber-deck bridges with concrete decks.
- Maintaining urban and rural road networks.
- Upgrading all unpaved roads to fair or good condition.
- Involving the private sector in the monitoring and operation of road transport services.
- Implementing appropriate road user charges.
- Harmonizing the country's highway code, road signs, signals and axle-load regulations within the region.
- Improving information coordination on the flow of regional and international cargo through the development of private sector freight forwarding companies.

- Creating one-stop border posts on all major transport corridors for the smooth flow of traffic and developing an integrated approach to road safety.
- Decreasing the number and severity of traffic accidents.
- Increasing the use and ownership of non-motorized and motorized means of transport.

2-1-1-2 Development Plan for the Transport Sector in PSIP

The Public Sector Investment Programme (PSIP) has been formulated for the purpose of implementing the prioritized investment projects that are most closely related to the MGDS. As the rolling plan for the public sector investment in the next five years (from July 2006 to November 2010), it provides a comprehensive list of prioritized public projects/programs. The objectives of the PSIP are as follows.

- To improve economic management so that the macroeconomic strategies of the MGDS are reflected in various programs/projects.
- To improve aid coordination and to promote focusing of external sources (funds from donors) on priority areas.
- To establish project cycle management through strengthening and better management of the preparation, evaluation, implementation, and monitoring of projects.
- To establish the past data for public sector investment and the planned future levels.
- To strengthen the influence of the government of Malawi in negotiations with donors.
- To promote financial management through various means such as multiple-year budget planning.
- To provide the citizens of Malawi with the information on the issues regarding public investment.

2-1-1-3 Overall Goals and Project Goals

The overall goals and the project goals of this project are as follows.

- Overall Goals

  Promotion of the economic growth of Malawi through the improvement of "Main Road No. 1," which is a main artery for both domestic and international road transport.

- Project Goals

  Main Road No. 1 is a 1,108-km trunk road running through Malawi in north-south direction from Songwe on the Tanzanian border to Marka on the Mozambican border. Mail Road No. 1 takes an important role in physical distribution in the country. In combination with Main Road No. 5 along Lake Malawi in the eastern part of the country, this road is also expected to serve as an international trunk road for physical distribution between Malawi and Tanzania, Mozambique, and South Africa.

  The existing Rukuru Bridge (cf., the new bridge is called the "South Rukuru Bridge") is a one lane bridge despite its location on Main Road No. 1, and is causing a bottleneck in traffic and physical distribution. In addition, this bridge is a temporary structure (a Bailey bridge), which has become decrepit after more than 30 years of use. Furthermore, the South Rukuru River flowing beneath the Rukuru Bridge is joined by a tributary Lura River at a location 30 m of the upstream from the present bridge, and the site is filled with deposits of boulders, driftwood, etc. form the Lura River.

  The purpose of this project is to eliminate the traffic bottleneck by replacing the narrow (one lane) and decrepit existing Rukuru Bridge, envisioning the activation of international physical distribution, economic development of surrounding areas, and poverty reduction.

2-1-2 Basic Concept of the Project

To attain the above-mentioned goals, this project intends to replace the existing Rukuru Bridge over the South Rukuru River using the grant aid assistance. The direct effects of the implementation of this project will include the elimination of the traffic bottleneck resulting from the narrow width and other factors, the abolishment of load restrictions resulting from insufficient load-bearing capacity, and the improved safety of pedestrians, bicycles, etc. As a result, this project is expected to serve for the development of international physical distribution, vitalization of local economy, improvement of living standards, poverty reduction, etc.

2-2 Outline Design of the Japanese Assistance

2-2-1 Design Policy

This project intends to replace the existing Rukuru Bridge and construct its access roads for the purpose of improving the present situation where the existing bridge is causing a traffic bottleneck due to its narrow width and decrepit condition. This project is thereby expected to serve for the promotion of traffic and personal exchange between Malawi and neighboring countries, the realization of the function of an international trunk road, and the development of local economy. Based on the request from the government of Malawi, the results of field study, and the results of discussion, the plan is developed in accordance with the following policy.

2-2-1-1 Basic Policy

The design policy to be used in developing the basic plan is as follows.

(1) Scope of Assistance

The formal request for grant aid regarding this project was submitted from the Malawi side to the Japanese Embassy in 2007. This request described the project as the replacement of the 65.1-m long Rukuru Bridge over the South Rukuru River. However, during the preliminary study in August 2008, bank protection was also identified as part of request, and was included in the M/D.

The preparatory study described here was conducted chiefly for the purpose of reconfirming the contents of the request, as well as confirming bridge location and access roads, the profile plan of the bridge and access roads, provision of parking zones, width configuration, bridge type, alteration of the riverbed of the Lura River, procedures related to environment, natural conditions, and other factors. As a result of discussion with the Malawi side, it was finally confirmed that the main contents of the request for Japanese grant aid are as follows:

- Construction of a reinforced concrete bridge (2 lanes)
- Bank protection work
- Construction of access roads
- Installation of sidewalks
- Removal of boulders and driftwood associated with bridge construction.
-

(2) Bridge Location and Access Roads

Regarding the location of the bridge, the initial comparative evaluation of five proposals concluded that the proposal No. 3 (25 m of the downstream) would be the most appropriate because of the following reasons.

① The bridge construction cost would be the smallest of all the proposals, because length of the bridge would be the shortest.
② There would be no need for a temporary bridge and detour route for construction work, because the existing bridge and the existing roads can be used.
③ The impact by boulders and driftwood would be smaller than that in other proposals.
④ There would be very limited need for relocation of inhabitants and demolishing of houses.

Following the secondary comparative evaluation of proposal No. 3, it was concluded that the best location would be 16 m of the downstream on the A1 side and 19 m of the downstream on the A2 side because of the following reasons, and the modified proposal No. 3 was selected.

① The original horizontal alignment would involve a curvature in the bridge part. Construction of a curved bridge using PC post-tensioned beams is technically and practically difficult. It is desirable that the horizontal alignment of the bridge part is rectilinear.
② A straight bridge at 25 m of the downstream would require more cuttings on the slope of the mountain foot on the right bank and a longer runoff section length on the Karonga side.
③ Even if a nearer location at 15-20 m of the downstream is selected, more cuttings on the slope of the mountain foot would be required if the new bridge is parallel to the existing bridge.
④ The new bridge with an oblique angle to the existing bridge would minimize the cuttings on the slope of the mountain foot and shorten the runoff section length.

Surveying and boring were conducted along the alignment of this modified proposal No. 3, as well as hydraulic/hydrological studies, topographic surveying, and river surveying.

(3) Scale and Other Factors

1) Profile Plan of the Bridge and Roads

Regarding the vertical height of the bridge and roads, the comparative evaluation of three proposals concluded that the proposal No. 3 (2.5 m raising) would be the most appropriate because of the following reasons.

① Hydraulic and hydrological analysis showed that the flood level after removal of boulders to secure sufficient flow cross-section would be about 1 m below the present bridge road surface level.

② The hearing survey of local inhabitants revealed that the reports of past flooding (2002 and 2006) submerging the upper part of the present bridge parapet (about 80 cm from the bridge road surface) were only relevant to the flow cross-section reduced by boulders and other materials. (The flood level after securing sufficient flow cross-section would be as mentioned in □ above.)

③ The needed height of the new bridge (road surface height) is 3.5 m (2 m for the structural height of the new bridge plus 1.5 m for a safety margin) above the flood level.

④ From the above □-□, the needed height of the new bridge would be 3.5 m above the flood level, provided that the flood level is 1 m below the present bridge road surface level, and therefore 2.5 m would be the appropriate value for the raising of the bridge and the access roads.

⑤ Although locating the bridge on the downstream side would require cuttings on the slope of the mountain foot on the right bank, the extent of cutting may be minimized by raising the profile.

⑥ Because the area on the left bank (the Karonga side) is farm fields without houses, raising of the profile would cause no problems.

⑦ Even with a 2.5-m raising, parking zones may be secured by shifting the horizontal plan of the new bridge and access roads 16-19 m of the downstream for the sake of environmental and social considerations.

2) Span Length

The span length, determined by the following formula, is at least 26 m.

Span length $L = 20 + 0.005\,Q = 20 + 0.005 \times 1200\ m^3/sec = 26.0\ m$
where, Q is the planned high water flow rate (1200 m^3/sec).

3) Scope of Assistance Regarding the Access Roads

Because the bridge location would be shifted to a position 16-19 m of the downstream from the existing bridge, new access roads would be required in the runoff segments leading from the new bridge to the existing roads. These access roads will be constructed using Japanese grant aid, and the scope of assistance will be 321 m on the Mzuzu side and 306 m on the Karonga side.

4) Creating of Lay-bys

After the replacement of the bridge, the road will have 2 lanes and the humps at the both ends of the existing bridge will be removed, eliminating the need for vehicles to slow down or stop at the ends of the bridge and thereby spoiling the commercial opportunities for the small stores at the foot of the existing bridge. For the sake of environmental and social considerations, MOTPI and RA desire to have lay-bys near the access roads so that the commercial opportunities of these small stores may be ensured.

It is desirable to create a lay-by along the up line and one along the down line. These will be located near the present commercial establishments on the Mzuzu side and making use of a farm field on the Karonga side.

(4) Contents of Request and Items Discussed and Confirmed

The outline design will be developed according to the conditions agreed mutually by the two countries and the study team. The contents of request and the items discussed and confirmed during the preliminary study and the preparatory study are shown in Table 2-2-1.

Table 2-2-1 Contents of Request and Items Discussed and Confirmed

Item		Contents of request	Items discussed and confirmed	
			Preliminary study	Preparatory study
Target bridge		Replacement of the Rukuru Bridge	Replacement of the Rukuru Bridge	Replacement of the Rukuru Bridge
Bridge location		Not specified	Four proposals were presented: ・No. 1: 15 m of the upstream ・No. 2: location of the existing bridge ・No. 3: 25 m of the downstream ・No. 4: 25 m of the downstream	Modified proposal No. 3 was selected ・Modified No. 3: 16 m of the downstream on the side of A1 abutment 19 m of the downstream on the side of A2 abutment
Bridge elongation		65.1 m	Approx. 65-75 m	74.0 m
Width	Total width		9.7 m	10.5 m
	Roadways		3.65 m×2	3.35 m×2
	Shoulders			0.3 m×2
	Sidewalks		1.2 m×2	1.2 m×2
Number of lanes			2 lanes	2 lanes
Design vehicle speed				80 km/h
Design live load			B live load	B live load
Access roads			160 m-370 m	627 m

2-2-1-2 Policies Concerning Natural Environmental Conditions

(1) Weather

1) Temperature, Humidity, and Wind Speed

The monthly mean temperature in Bolero, the observation point nearest to the bridge site, drops to the lowest level of about 17°C in July and rises to the highest level of 26°C in October. The monthly maximum temperature varies in the range from 25 to 32°C throughout the year, peaking in November to 31.9°C in the 10 year average. The minimum temperature drops below 10°C in June and July, although it is about 16°C in the 10 year average. The annual range of temperature is about 13°C.

Humidity is in the range from 40% to 80% with the annual mean of about 60%. It peaks to 80% in January in the rainy season and drops to 40% in October in the dry season. Although humidity is not particularly high in this district, the bridge site becomes considerably hot and humid during the rainy season. Therefore, extreme care must be taken to develop a design considering temperature changes in structural members and to perform construction work considering concrete placing and curing. It must be taken into consideration that a steel bridge, if used in a hot and humid area, involves the problem of corrosion, which may also seriously affect on maintenance in the future.

Wind speed varies in the range from 0.5 to 2.4 m/s throughout the year. Wind tends to be stronger in the period from August in the middle of the dry season to October, and weaken after the beginning of the rainy season. With the annual mean wind speed of 1.2 m/s, this area is not subjected to particularly windy conditions. The data for wind direction are not available.

2) Rainfall Quantity and Pattern

The annual rainfall at the project location is about 670 mm in the 5 year average, showing a wide yearly variations ranging from 400 mm to 900 mm. Generally in Malawi, the dry season extends from

April to November, and the rainy season from December to April. In Bolero, rainfall decreases gradually in April and there is practically no rain from May to September. Rainfall increases in the period from October to December.

The area including the bridge site has clearly defined rainy and dry seasons, and most of rainfall in this area is concentrated in the rainy season (from December to April). These weather records represent a factor strongly affecting work plans and process plans, and the development of these plans must be conducted paying sufficient attention to these weather conditions. In particular, works in the river such as bridge pier substructure works and foundation works should be planned for completion during the dry season.

3) River Channel Features

i) South Rukuru River

The South Rukuru River has the basin area of 12,083 km^2, which is the largest among the rivers in Malawi. The river basin is located west of Lake Malawi, extending about 200 km north-south and about 60-90 km east-west. Major cities in this extensive area include Mzuzu and Mzimba.

The location of the new bridge is about 15 km upstream of the river mouth flowing into Lake Malawi. The river at this location has the width of about 60 m, and this relatively small river width for the large basin area creates a fast-flowing stream. There are many exposed rocks in the riverbed downstream from Jalawe Bridge near Phwezi, which is about 20 km upstream from the project bridge site. Located between mountain ranges, the river channel in this segment is narrow and steep with a succession of rapids and cataracts down to about 5 km before the river mouth flowing into Lake Malawi. On the other hand, the area upstream from Phwezi has broad flood plains with the width of about 2-3 km. The river in this area has gentle river-bed slope and meanders, and the upstream area has many expanses of marshes collecting water from the southern part of the catchment area. The flow from Rumphi carries the water from the northern, western, and southern parts of the basin area.

The location of the bridge should be determined sufficiently considering these river channel features.

ii) Lura River

The Lura River with the basin area of 153 km^2 is a tributary flowing into the South Rukuru River. A part of the western half of the catchment area is located within Nyika National Park. The main stream of the Lura River runs from a steep mountainous terrain, traverses a flatland for a while, and then flows down a steep mountainous terrain in the area near the confluence with the South Rukuru River, which occupies about 1/3 of the total basin area.

The condition of the river near the confluence point is that the river enters a mountainous area immediately after confluence, and the river flows along the valley in the steep mountainous terrain stably with largely constant width and slope. The width of the main stream is about 20 m, and the flow rate is not particularly large.

About 1/3 of the Lura River basin is occupied by flatlands and hills. There are no large retention areas, and the runoff coefficient may be calculated applying the values for mountainous areas, farmlands, and hills according to land use.

4) Floods

At the location of the existing bridge, there have been 4 floods (2001, 2002, 2003, and 2006) since 2000. Because these floods caused deposition of soil and driftwood carried by flood water, burying a 20-m wide (1/3 of the river width) 70-m long area, the river channel cross-section has diminished and the floodwater carrying capacity has become insufficient. In the event of a future flood, this reduced river channel cross-section may cause a rise of water level upstream from the bridge, and even a moderate flood may result in a flow running over the bridge. This study, making an assumption of the design flood at the bridge location, will develop a bridge plan that would be immune from the impact of floods when sufficient flow capacity is secured through the removal of soil and rocks currently clogging the river and the improvement of river channels both upstream and downstream from the bridge.

5) Design flood discharge

According to the probability estimation of the annual maximum of daily mean flow based on the data for the South Rukuru River obtained from the preliminary study, the maximum flow is calculated to be 400 m^3/s at the probability of 1/50. The Lura River has the width of about 40 m and the slope of 1/50. Assuming the water depth of 1.5 m and the roughness coefficient of 0.035, the flow volume corresponding to the flow capacity is Q = 303 m^3/s. Because the daily rainfall at the 1/50 probability is 90.6 mm/h, the rational formula gives 487 m^3/s from the basin area A_{Lura} = 153 km^2, f = 0.7, and r = 16.4 mm/h. Similarly, for the residual basin area of the South Rukuru River, the rational formula gives 363 m^3/s from the basin area A_{Rukuru} = 130 km^2, f = 0.7, and r = 14.4 mm/h. Assuming that the South Rukuru River and the Lura River reach the peak simultaneously at confluence, we obtain:

Design Flood Flow = 400 + (303)487 + 363 = 1,066 to 1,250m^3/s.

The peak flow values have been calculated somewhat exaggerated, because the flow volume values in the residual basin areas of the tributary Lura River and the South Rukuru River are the values calculated assuming no retention and this calculation is usually applied to the case with the basin area of 100 km^2 or less. Considering this fact, it may be assumed that the design flood discharge at the bridge location is 1,200 m^3/s.

6) Scouring and Depth of Foundation Structure Placement

The height of bridge pier foundations will be determined considering scouring around bridge piers. Regarding the scouring depth, the Japanese standards demand a scouring depth of 2.0 m or more measuring from the design river bed level or the lowest river bed level, whichever the lower. Therefore, in this project, bridge pier footings will be designed with the embedment depth of at least 2.0 m from the lowest river bed level or the embedment into the bedrock. With respect to abutments, footing bases will be designed with sufficient penetration into a good supporting layer such as bedrock, hardpan, or gravel in the case of spread footing. In addition, foot protection will be used whenever necessary.

(2) Earthquake-resistant Design

Belonging to the Pan-African mobile belt, Malawi is located in the Nyasa Rift Valley, which is the southernmost part of the tectonic collapse zone (the East African Rift) ranging north-south from the Red Sea to Eastern Africa over the distance of 6,000 km. The activity of this East African Rift, which started about 40 million years ago, continues nowadays, showing the expansion at the approximate rate of 5 mm a year. Lake Malawi, with its north-south elongated shape, is a fault lake formed by this movement. A part of the Malawi Rift (over 3 km thick) is seen exposed in Livingstonia Mountain above the west shore of the lake. This study, reviewing the severity of past earthquakes in Malawi, will develop a design that can resist an earthquake equivalent to the one that occurred in central Malawi on March 10, 1989, causing 3 deaths and over 60 injury cases. In addition, coherence with the Southern Africa Transport and Communications Commission’s specifications “Code of Practice for the Design of Road Bridges and Culverts 2001” will be sought and reflected in the earthquake-resistant design.

2-2-1-3 Policies Concerning Traffic Volume

(1) Basic Policy in Traffic Demand Projection

The volume of the traffic using the existing Rukuru Bridge has been estimated to be about 290 vehicles/day based on the past surveys conducted in the vicinities and the results of the preliminary study. About a half of this volume is occupied by trucks and similar vehicles, reflecting the important role of this road as an international trunk route for physical distribution.

In this study, traffic volume surveys were conducted for the purpose of collecting traffic volume information needed for the facility plan, design, and construction of the target bridge “Rukuru Bridge”, as well as grasping variations by day of the week, daytime and nighttime traffic characteristics, directional traffic volumes in various time zones, and non-motorized traffic volume (pedestrians and bicycles).

(2) Overview of Automobile Traffic Volume

- The automobile traffic volume on Rukuru bridge is about 200 to 280 vehicles/12h in cross-section (bidirectional).
- The number of passenger cars is relatively small, and most of the traffic volume is occupied by commercial vehicles (buses, trucks, etc.)
- The percentage of large vehicles (trucks with 3 or more axles) is relatively high, being about 15-20% on weekdays and 20-25% on holidays.
- Foreign-registered vehicles (Tanzania, Zambia, and South Africa) represent 65% of all vehicles, indicating the important role of this bridge in the international physical distribution of Malawi, in addition to the important role in the living of local inhabitants.
- The day-night ratio (24-hour traffic volume/12-hour traffic volume) is relatively high, being 1.46 on weekdays and 1.28 on holidays.

(3) Estimated Traffic Volume

The Table below shows the 24-hour traffic volume estimated from the results of traffic volume surveys.

Table 2-2-2 Estimated Traffic Volume

Direction	Date	Day	Pedestrian	Bicycle	Motorcycle	Passenger car	Bus and Microbus	Light truck (2 axles)	Heavy truck (3 axles or more)	Others	Total
Mzuzu→Karonga	16/03/2009	Mo	305	8	1	51	32	39	42	0	478
	17/03/2009	Tu	291	10	5	39	44	58	42	0	489
	18/03/2009	We	267	10	2	58	36	50	55	0	478
	19/03/2009	Th	328	3	0	37	33	53	29	0	483
	20/03/2009	Fr	370	10	3	60	36	36	61	0	575
	21/03/2009	Sa	201	20	2	51	29	49	59	0	411
	22/03/2009	Su	287	15	2	43	29	37	31	0	444
	Total		2,049	76	15	338	238	323	319	0	3,358
	Daily mean (total)		293	11	2	48	34	46	46	0	480
	Daily mean (vehicles)		-	-	-	-	-	-	-	-	176
	Percentage (total)		61%	2%	0%	10%	7%	10%	10%	0%	100%
	Percentage (vehicles)		-	-	1%	27%	19%	26%	26%	0%	100%
Karonga→Mzuzu	16/03/2039	Mo	327	8	2	26	30	46	44	0	483
	17/03/2009	Tu	331	6	3	23	37	44	73	0	517
	18/03/2009	We	350	11	2	49	33	61	70	0	576
	19/03/2009	Th	345	5	3	60	28	60	19	0	520
	20/03/2009	Fr	374	18	3	45	37	46	70	0	593
	21/03/2009	Sa	281	21	4	68	33	32	35	0	474
	22/03/2039	Su	310	14	5	49	31	32	36	0	477
	Total		2,318	83	21	320	230	322	346	0	3,640
	Daily mean (total)		331	12	3	46	33	46	49	0	520
	Daily mean (vehicles)		-	-	-	-	-	-	-	-	177
	Percentage		64%	2%	1%	9%	6%	9%	9%	0%	100%
	Percentage (vehicles)		-	-	2%	26%	19%	26%	28%	0%	100%
Total of both directions	16/03/2009	Mo	631	16	3	77	62	85	87	0	960
	17/03/2009	Tu	622	16	8	62	81	102	115	0	1,006
	18/03/2009	We	617	21	4	107	68	112	125	0	1,054
	19/03/2009	Th	673	8	3	97	61	113	48	0	1,003
	20/03/2009	Fr	744	28	6	105	73	83	130	0	1,168
	21/03/2009	Sa	482	41	6	119	62	81	94	0	885
	22/03/2009	Su	597	29	7	92	60	69	67	0	921
	Total		4,367	159	36	659	467	645	655	0	6,998
	Daily mean (total)		624	23	5	94	67	92	95	0	1,000
	Daily mean (vehicles)		-	-	-	-	-	-	-	-	**353**
	Percentage		62%	2%	1%	9%	7%	9%	10%	0%	100%
	Percentage (vehicles)		-	-	1%	27%	19%	26%	27%	0%	100%

2-2-1-4 Policies Concerning Bridge Width

The width configuration shown in Fig. 2-2-1 is employed in accordance with the standard width configuration of roads in Malawi (Table 2-2-3).

Table 2-2-3 Standard Width Configuration of Roads in Malawi

	Roadway Width	Sidewalk Width	Bicycle	Shoulder	Total
Trunk Road	6.7 m	1.2 m(both sides)	0.3 m(both sides)	—	9.7 m
Secondary Road	<6.7 m>	<1.5 m(both sides)>	<1.5 m(both sides)>		<12.7 m>
Tertiary Road	5.5 m	—	—	2.1 m(both sides)	9.7 m
Rural Road	3.65 m	0.6 m(both sides)	—	—	4.85 m
Urban Road					

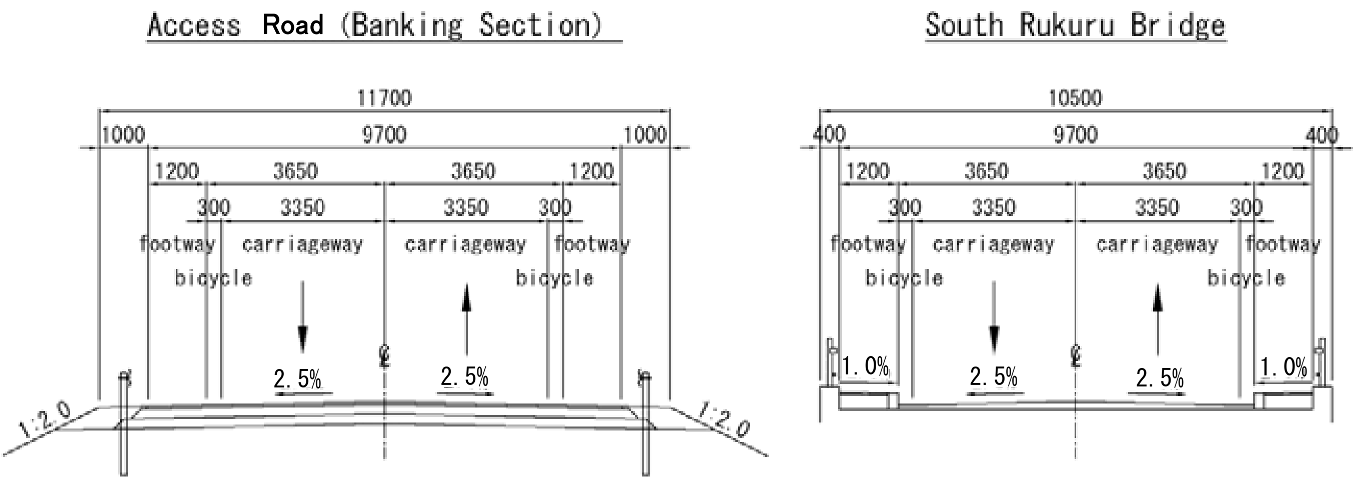


Fig. 2-2-1 Width Configuration of Roads and Bridge

2-2-1-5 Policies Concerning Design Live Load

Regarding the design live load, our examination comparing the BS5400 HA load and HB load defined in Malawi's Bridge Design Manual of Malawi with the B live load defined in Japan's Specifications for Highway Bridges indicated the appropriateness of B live load. Therefore, B live load will be used.

2-2-1-6 Policies Concerning Socioeconomic Conditions

The following items and measures should be taken into consideration in planning, designing and constructing the bridge to be provided under the Project.

① Dust to be generated in the course of construction: Implement dust-prevention measures, such as water spraying.
② Noise and vibration resulting from the construction works: Adopt such methods that keep noise and vibration to a minimum.
③ Spills of pollutants (oil, etc.): Take necessary measures to prevent any spill of pollutants.
④ Soil flowage and contamination of the river: Take necessary measures to prevent soil flowage and contamination of the river.
⑤ Obstruction to the general traffic: Provide safety education to construction vehicle drivers.
⑥ Barrow pits and quarries: Select locations with less pressure to the environment as barrow pits. Maximize the utilization of the existing quarries so as to avoid quarrying at new locations.
⑦ Accidents: Prevent any accident from happening by providing the personnel engaged in the construction works with thorough education on safety and hygiene.

In addition, it has been confirmed that no relocation of inhabitants is needed in the scope of this Project.

2-2-1-7 Policies Concerning Construction

(1) Status on workforce

While there are construction companies, engineers and workers involved in construction of bridges, which were funded by past grant aid, their numbers and experiences are limited. In particular, expertise and experiences in prestressed concrete bridge construction are extremely limited. Hence, certain types of work that require expertise and ones with few implementation records will be implemented by engineers dispatched from Japan. The remaining work will, in principle, utilize the local engineering/labor resource.

As in the case with past grant aid projects, it is possible to procure workers within Malawi. However, since they belong to different construction companies, each of which has its own specialty in specific areas of construction, it is important to consider these differences. When employing workers, the employer must comply with the Malawian Labor Law (enacted in 2000.)

(2) Status on procurement

1) Reinforcing bars, steel products and prestressed concrete steel

Since reinforcing bars are not produced in Malawi, they will be procured from third countries such as South Africa. Design and procurement need to fully take into account radius and rug geometry of reinforcing bars, some of which are different from those in Japan.

Since steel products including steel plates and shaped steel materials are also not produced in Malawi, they need to be procured from either Japan or third countries (e.g. South Africa). In addition, prestressed concrete steel can be hardly procured in the general market, and at the same time there are no processing facilities with reliable expertise. Hence, order placement of prestressed concrete steel used for this project will require a set of measures for quality assurance such as specifying import origins/manufacturers, and use of imports from Japan or third countries shall be considered.

2) Bridge attachments

As in the case with past grant aid projects, some of bridge attachments can be procured from the neighboring countries, but there are many quality problems. Hence, attachements procuded from Japan are considered desirable.

3) Cement

Because there is limited production of cement in Malawi, the material, which is usually limited to Portland cement, is usually imported from the neighboring countries. According to the RA counterpart, cement imported from Tanzania, a country neighboring to the site, has quality problems.

Under the circumstance, adoption of the above cement in prestressed concrete girders that require strength is considered difficult, and instead imports from South Africa, including early-strength cement shall be used in consideration of its problem-free quality and supply volume.

4) Asphalt concrete

There seem to be no operator that possesses an asphalt plant in the proximity of the site. In Malawi, pavement operators move their simplified asphalt plants to construction sites under their contracts with builders and conduct paving work. Therefore, asphalt shall be considered subject to outsourcing work.

5) Aggregate

For concrete aggregate and paving for access roads, preferably a quarrying plant will be built near the site, and will use sediments on the left bank of the existing river bed. In case when there is a shortage in stone aggregate, it will be supplemented with extraction/transfer from Rumphi (approximately 50 kilometers from the site).

6) Embankment materials

It was confirmed that embankment materials from the Phwezi (existing) borrow pit (21 kilometers from the site) reported in the preliminary study were considered appropriate.

(3) Procurement of construction equipment

As a result of the study on equipment possessed by building constructors in Lilongwe to investigate equipment needed for bridge construction, it was confirmed that procurement of caterpillar-type heavy equipment was difficult. Also, while general machines for civil engineering can be procured from Lilongwe and Mzuzu, many of them are used types. Hence, planning of equipment procurement needs to take the backup process into consideration.

(4) Road/bridge design and construction standards

1) Road design/construction standards

Road design will comply with the standard established in Malawi, and areas not covered by the standard will follow a Japanese standard. Hence, design standards adopted in road design are as follows;

- HIGHWAY DESIGN MANUAL 1978 (MINISTRY OF WORKS AND SUPPLIES)
- Code of Practice for the Geometric Design of Trunk Roads 1998 (SATCC)
- Road Structure Standard (JAPAN)

2) Bridge design/construction standards

In bridge design, standard strength of locally procured materials will adopt a Malawian design standard, and live load and design methods will adopt a Japanese standard. Hence, design standards adopted in bridge design are as follows;

- BRIDGE DESIGN MANUAL 1988 (MINISTRY OF WORKS AND SUPPLIES)
- Code of Practice for the Design of Road Bridges and Culverts 1998 (SATCC)
- Road Bridge Standard 2002 (JAPAN)

2-2-1-8 Policies Concerning Utilization of Local Operators

As a result of an interview survey conducted with local operators and neighboring countries' building constructors, it was found that Malawian operators have participated in construction of wide-span bridges as contractors under joint venture. Also, according to an interview survey with local consultants, their services are confined to measurement, geological surveying, traffic analysis and environment surveying, etc. due to their capacity.

2-2-1-9 Policies Concerning Handling of Operation/maintenance Management Capabilities

Operation of this project at the Malawian side and maintenance management after completion will be implemented by the country's Roads Authority.

The Roads Authority (RA) used to be called the National Roads Authority, which was separated into the operative function (RA) and the accounting function (Road Fund Administration: RFA) by following World Bank's recommendation in 2007 to improve the efficiency of its operations. RA's project implementation method was also changed from the force-account system to hiring private contactors using the budget appropriated by the government to RA. The function of the Roads Authority is supervision of road construction/rehabilitation/maintenance management, and supervision of paid/grant aid work by overseas funding is also implemented under the jurisdiction of Ministry of Transport & Public Infrastructure.

Operational policies will be decided by the Board of Directors. The Design Department, Construction Department, Maintenance Management Department, Finance/Control Department, ICT Department and Procurement Department are placed under the Director General, and three regional offices- South, Central and North Offices are placed under the Maintenance Management Department.

The number of staff in the Roads Authority as of 2009 is 104, consisting of 4 general managers, 55 road/bridge engineers and 45 administrators etc. Maintenance management has been all implemented under contracts with builders, and on-site management has been done by hired consultants.

Maintenance management after completion of bridge construction under this grant aid is expected to be done by the North Office of the Roads Authority. There are no particular problems associated with maintenance management of the bridge as RA is experienced in maintenance management, and laws concerning budget have been introduced sufficiently to the extent that even gasoline expenses can be recovered. Still, its structure shall adopt design that will allow as much simple maintenance management as possible.

2-2-1-10 Policies Concerning Setting of Facility Grades

The South Rukuru Bridge, the bridge built under this grant aid, will be located on Main Road No,1 that vertically stretches through Malawi, and is considered a highly important bridge as it will be also on the international trunk road that supports distribution between the country and Tanzania, Mozambique and South Africa, thereby adopting the following grades;

① Design standards：
- Road design will comply with the standard established in Malawi, and areas not covered by the standard must follow a Japanese standard.
- Bridge design: Standard strength of locally procured materials will comply with a Malawian design standard, and live load and design methods will comply with a Japanese standard.

② Design live load: B load defined in Japanese road/ bridge manuals shall be adopted.
③ Width：
- Bridge width: Roadway width: 3.35 m×2=6.7 m, Bicycle 0.3 m×2=0.6 m,
  Walkway 1.2 m×2=2.4 m Total 9.7 m
- Access road width: Roadway width, 3.35 m×2=6.7 m, Bicycle 0.3 m×2=0.6 m,
  Walkway 1.2 m×2=2.4 m
  Protection shoulder 1.0 m×2=2.0 m Total 11.7 m

④ Road type: Main road (national highway)
⑤ Design speed: 80km/h

2-2-1-11 Policies Concerning Work Methods and Schedule

(1) Policies concerning work methods

From the rainfall at the Bolelo weather observatory, it is estimated that the dry season for the South Rukuru Bridge area lasts eight months from April to November, and the rainy season is four months from December to March. However, the South Rukuru River has a flow area of as large as 12,083 sq., and is considered a river with the largest flow area in Malawi, presumably affecting the South Rukuru Bridge to a great extent during the rainy season. Furthermore, a two to three kilometer wide flood plain around the Phwezi area, which is located approximately 20 kilometers upstream of the bridge location, and many more wetlands stretching the area prevent the water level and flow velocity at the South Rukuru Bridge location from lowering even during the dry season. Also, the bridge location is the junction with its branch river, Lura River, which will also affect the bridge location with the flow volume.

The dry season starts in April, but neither the water level nor flow velocity of the South Rukuru River lowers significantly, and rich water volume and fast flow velocity that are similar to those of the rainy season are expected. While construction of a lower-part bridge (bridge piers, abutments) at the river is usually implemented during the water-scarce dry season, in the case of the South Rukuru Bridge, construction at the river has to start at the beginning of the dry season when both the water level and flow velocity are high. Hence, groundwork of the bridge piers and lower-part bridge construction will require careful attention to coffering and boring etc.

(2) Policies concerning work schedule

As stated above, the dry season in the South Rukuru bridge construction area has high water level and flow velocity even in its beginning, requiring efficient work planning that takes into account the conditions during the dry season and the fact that the rainy season is, in essence, longer than that of other regions of Malawi. Also, by positioning the bridge location 16 to 19 meters downstream of the existing Rukuru Bridge, access roads, one of which is 321 meter long at the A1 abutment (the Muzuzu side) and the other is 306 meters long at the A2 abutment (the Karonga side,) will be built to connect to the existing main road, and the construction process of the South Rukuru Bridge shall take into account the construction process of these access roads.

2-2-2 Basic plan

2-2-2-1 Basic Plan Work Flow

Basic Plan includes status survey, selection of a bridge location, study on bridge vertical planning, study on a parking bay, study on modification of the Lura river channel, definition of the bridge size, study on a bridge type and other tasks needed for implementation of this project to determine a bridge type. The following diagram shows the work flow of the basic plan.

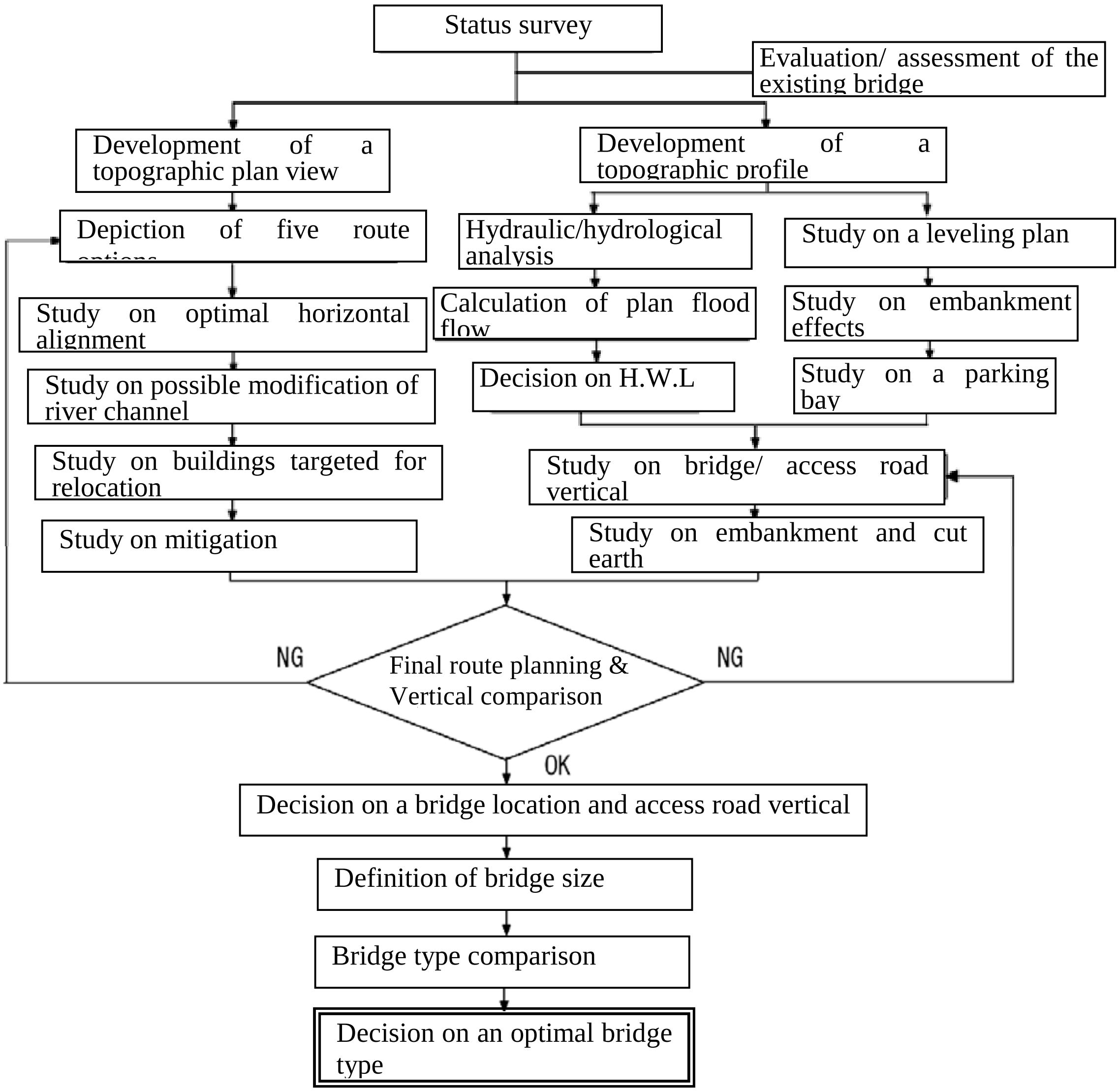


Fig. 2-2-2 Basic Plan work flow

2-2-2-2 Current Status on the Bridge Location

Main Road No,1 is a 1,108 kilometer-long trunk road passing from the north to the south of Malawi, and is also an international highway that supports distribution between Malawi and Tanzania, Mozambique and South Africa. The existing Rukuru Bridge is a one lane bridge despite its location on Main Road No1, and is causing a bottleneck in traffic and physical distribution due to its temporary structure (a Bailey bridge,) which became decrepit after more than 30 years of use. Furthermore, the South Rukuru River running beneath the Rukuru Bridge meets with the Lura River 30 meters upstream of the current bridge location, where the deposition of bounding stones and driftwood coming from the Lura River has remained. Results of the study on the conditions around the existing Rukuru Bridge are shown in Fig. 2-2-3.

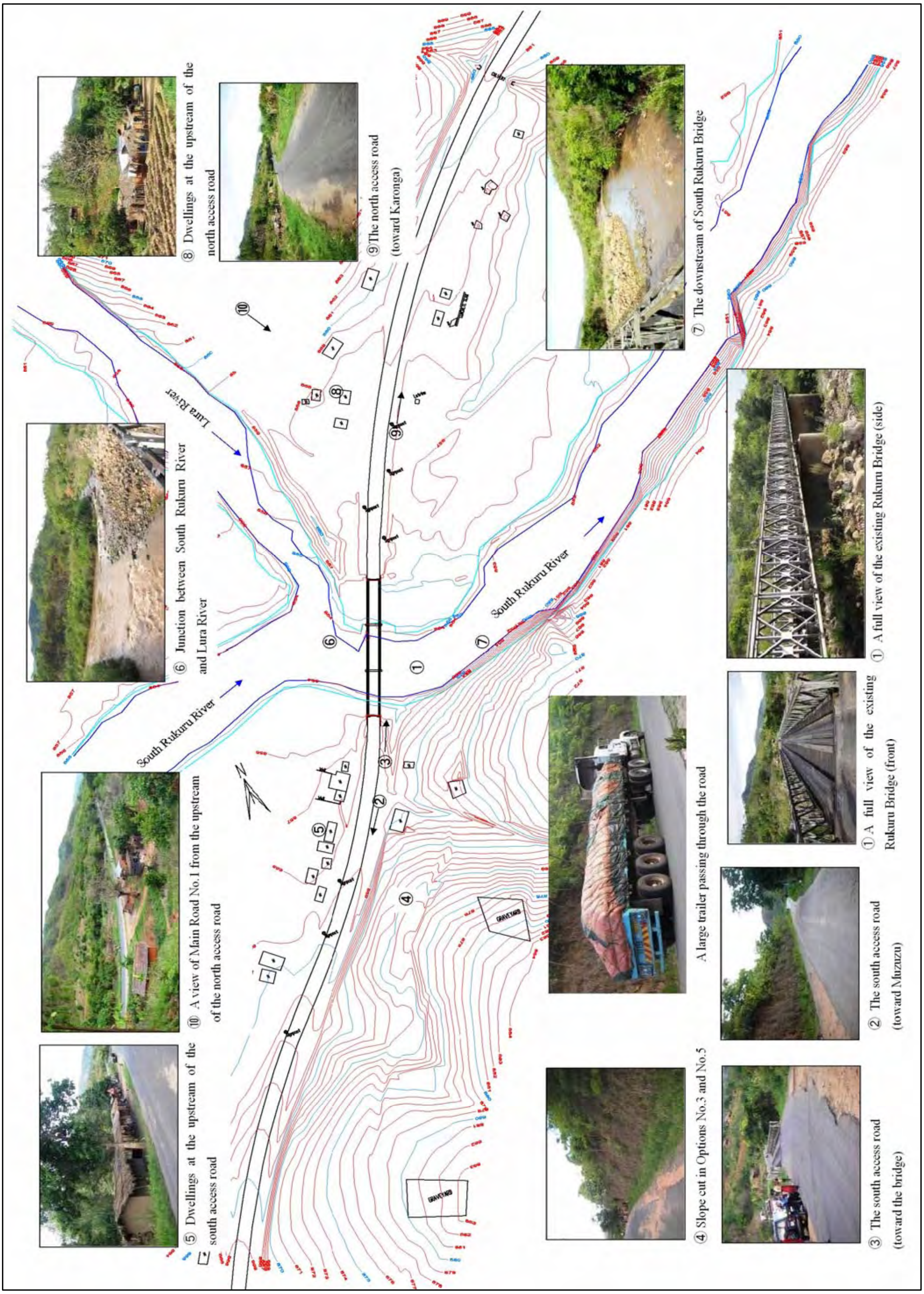


Fig. 2-2-3 Conditions around the existing Rukuru Bridge

2-2-2-3 Evaluation/Assessment of the Existing Rukuru Bridge

The existing Rukuru Bridge is a Bailey bridge built through the assistance from Kreditanstalt für Wiederaufbau (KfW) in 1980. After 30 years of use, the bridge is severely corroded and damaged, and its bearing capacity is insufficient due to the temporary structure. Furthermore, it has become a bottleneck in traffic since its 4.13-meter effective width with only one lane available, is not wide enough to allow two-way traffic on the bridge. Results of the study on the soundness of the existing Rukuru Bridge are shown in Table 2-2-4 and Fig. 2-2-4.

Table 2-2-4 Results of the study on the soundness of the existing Rukuru Bridge

<table>
<tr><td colspan="3">Bridge name</td><td colspan="3">South Rukuru Bridge</td></tr>
<tr><td rowspan="7">Specifications</td><td colspan="2">Year of establishment</td><td>1980</td><td>Positions</td><td>East longitude 34°7’26”, North latitude 10°45’44”</td></tr>
<tr><td colspan="2">Average daily traffic (vehicles/ day)</td><td>353</td><td>Distance</td><td>Approx. 500 kilometers from Lilongwe</td></tr>
<tr><td colspan="2">Effective width (Total width)(m)</td><td>4.13(5.6)</td><td>Percentage of large vehicles</td><td>Approx. 17%(daytime) – 30%(night time)</td></tr>
<tr><td colspan="2">Design live load</td><td colspan="3">Unknown [HB load (BS) or SLW, LKW load (DIN)]（BS）</td></tr>
<tr><td rowspan="2">Upper part</td><td>Bridge type</td><td colspan="3">Bailey bridge (Two-side, three-span suspension Bailey bridge)（timber deck）</td></tr>
<tr><td>Length(m)</td><td colspan="3">21.745+21.950+21.745=65.440 m</td></tr>
<tr><td colspan="2">Lower part</td><td colspan="2">Abutment: Reinforced concrete structure</td><td>Pier: Reinforced concrete structure</td></tr>
<tr><td rowspan="3">Study results</td><td colspan="2">Functionality（in traffic）</td><td colspan="3">・ While its average daily traffic of 353 vehicles/day is not relatively heavy, its functionality (role) is significantly high as Main Road No.1 is a highway that connects the north and the south of Malawi, and is also the Dar es Salaam International Corridor.
・ Effective width of the lane on the bridge is as narrow as 4.13m, making two-way traffic impossible.
・ The bridge is dangerous for pedestrians who have to walk on the roadway due to unavailability of a walkway.</td></tr>
<tr><td colspan="2">Soundness（Extent of damage）</td><td colspan="3">・ The bridge has become decrepit due to severe cracks in the bridge abutments and piers.
・ Severe corrosion on the girders and sway bracings. Upper lateral bracings have disappeared.
・ Truss members have been damaged due to vehicle collisions.
・ The bridge abutments and piers are buried with bounding stones and driftwood.
・ The timber deck is severely damaged.</td></tr>
<tr><td colspan="2">Structure performance（Stability）</td><td colspan="3">While the bridge is a temporary structure (Bailey bridge), it has structural and load capacity problems due to traffic of large trailers and its wooden deck.
・ Because of the high flow velocity, the bridge piers might have been scoured.</td></tr>
<tr><td colspan="3">Considerations</td><td colspan="3">・ With only one lane available, the narrow bridge width has become a bottleneck in traffic.
・ It has load bearing problems with live load of large trailers.
・ It has load bearing problems due to severe damage of the bridge abutments, piers and timber deck.
・ As a general consideration, due to its narrow width, unavailability of a walkway, severe damage of the deck/cracks in the lower part, its incapacity to support traffic of heavy vehicles and structural problems with the lower part, construction of a new bridge is considered desirable.
・ Removal of the existing bridge is necessary immediately after construction of the new bridge.
To secure a cross-sectional flow area, removal of bounding stones is also needed after flood.</td></tr>
</table>

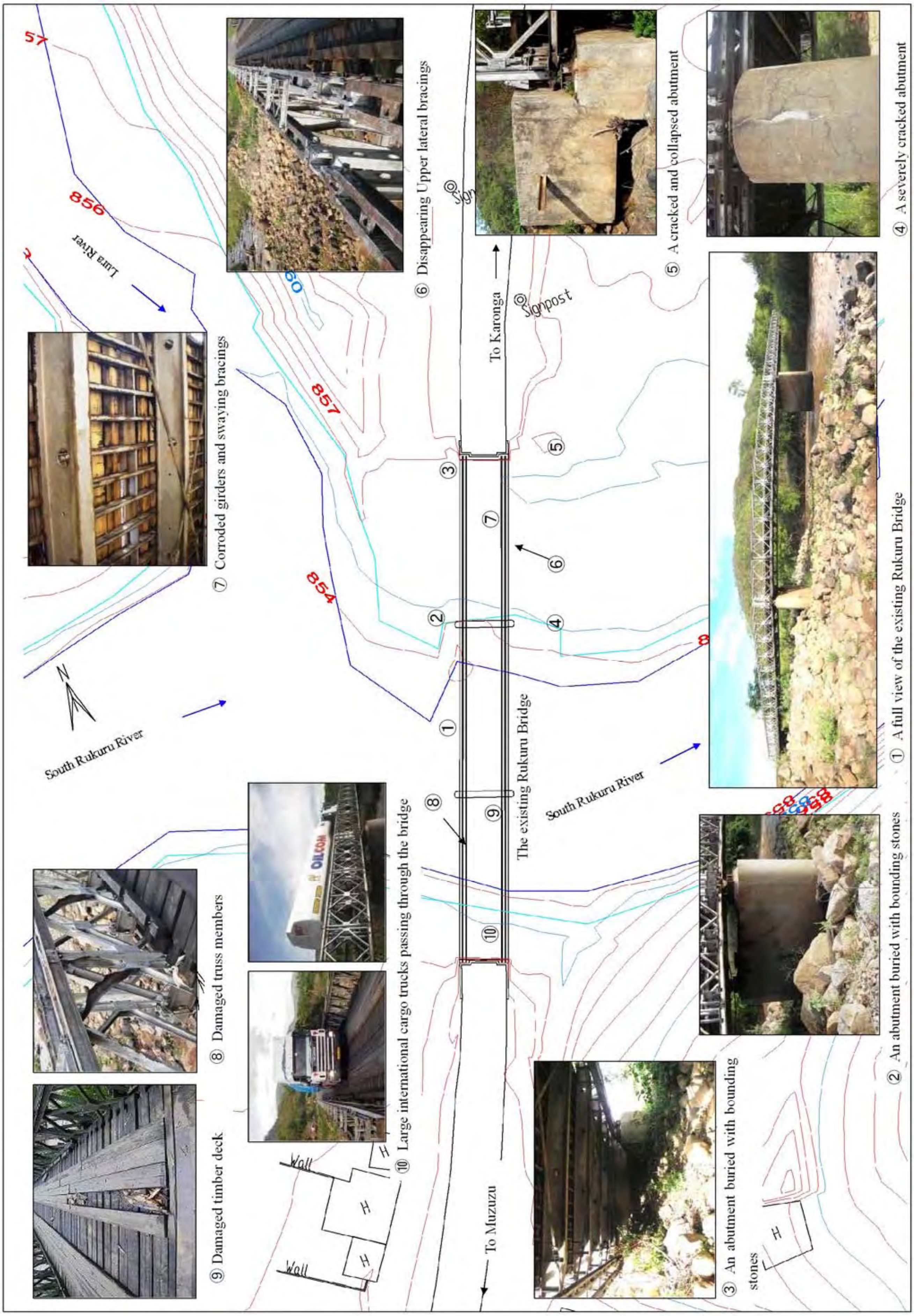


Fig. 2-2-4 Results of the study on the soundness of the existing Rukuru Bridge

2-2-2-4 Study on Bridge Locations

(1) The first comparison of different bridge locations

1) Selecting a bridge location

Replacement of the Rukuru Bridge, the bridge concerned in this study, is proposed provided that its narrow width only allows one lane despite its location on Main Road No.1, that the bridge is a temporary structure (Bailey structure) instead of a permanent structure and that the bridge has become decrepit due to more than 30 years of usage. As results of the study on linearity of Main Road No.1, conditions of the South Rukuru River and the Lura River and conditions of dwellings and shops of neighboring residents, the following five options were selected as options for a bridge location.

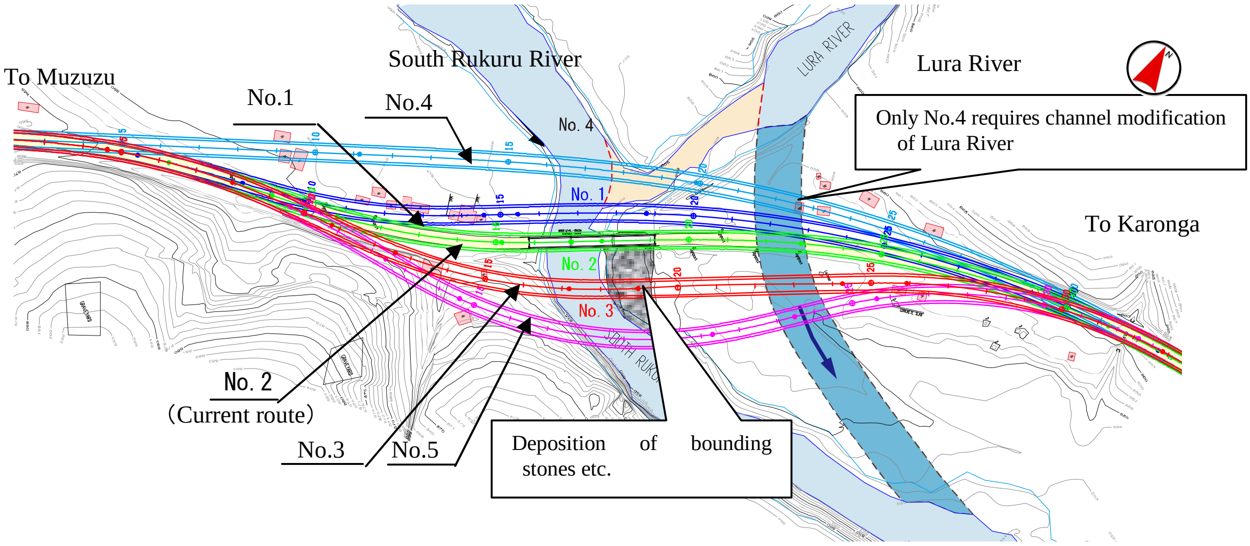


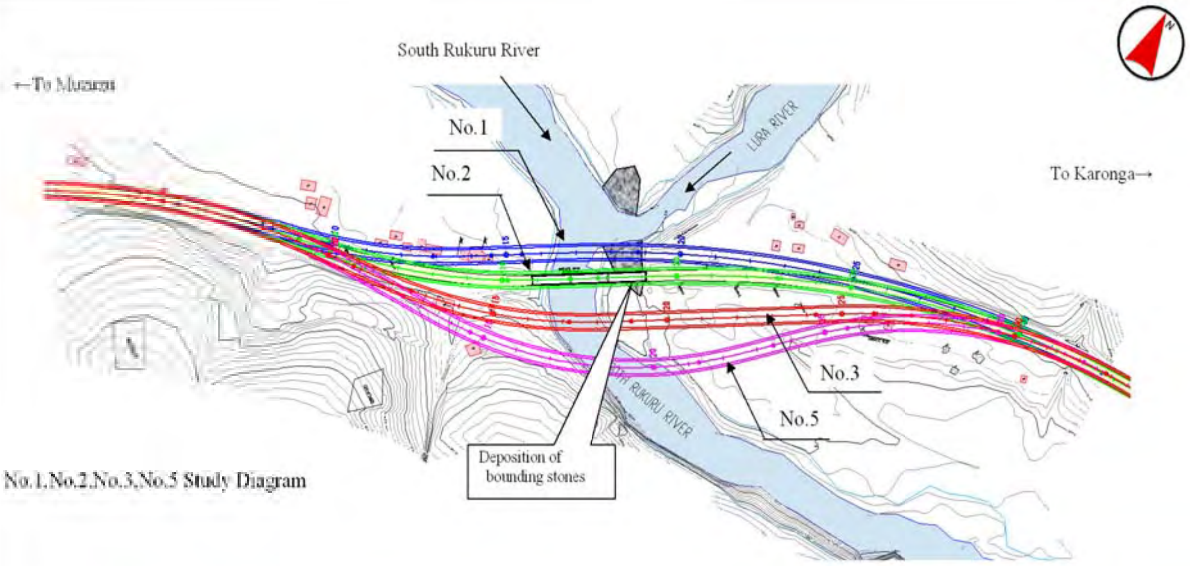
Fig. 2-2-5 Bridge Location (Option No.5)

- Option No.1（15 m of the upstream）
  The option proposed in the preliminary study report. In this plan, the new bridge will be built 15 meters upstream of the existing Rukuru Bridge.
- Option No.2（Current bridge location）
  The option proposed in the preliminary study report. In this plan, the new bridge will be built in the position where the existing Rukuru Bridge is located.
- Option No.3（25 m of the downstream）
  The option proposed in the preliminary study report. In this plan, the new bridge will be built 25 meters downstream of the existing Rukuru Bridge.
- Option No.4（25 m of the upstream + channel modification of Lura River）
  The option proposed in the preliminary study report. It requires modification of the Lura River channel to build the new bridge 25 meters upstream of the existing Rukuru Bridge.
- Option No.5（50 m of the downstream）
  The option proposed during this pilot study, in addition to the above four options proposed in the preliminary study report. In this plan, the new bridge will be built 50 meters downstream of the existing Rukuru Bridge.

2) Comparison of bridge location options

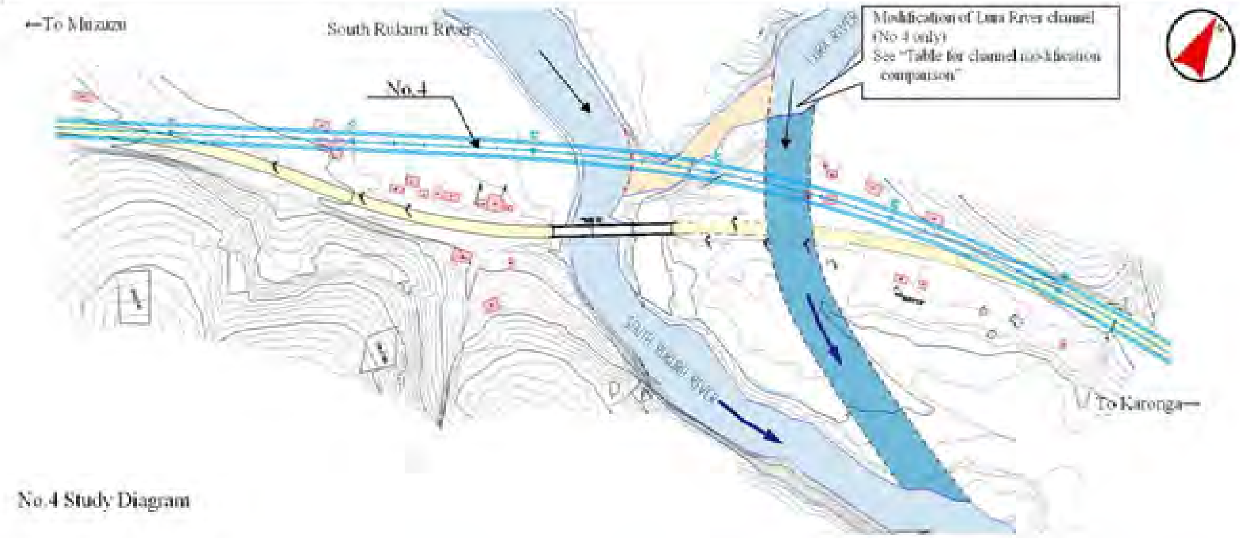
Table 2-2-5 shows results from the comparison of the five options selected as the first group of bridge location options.

Table 2-2-5 A table comparing bridge location options (1/2)



Options		Option No.1 (15 meters upstream)	Option No.2 (Current bridge location)	Option No.3 (25 meters downstream)
Option overview		· In this option, the bridge location will be shifted approx. 15 meters upstream of the existing bridge. · No modification to the channel of the Lura Branch River is required.	· In this option, the bridge will be replaced at the current location. · No modification to the channel of the Lura Branch River is required.	· In this option, the bridge location will be shifted approx. 25 meters downstream of the existing bridge. · No modification to the channel of the Lura Branch River is required.
Evaluation of options	Bridge length and economic efficiency	· The bridge length is 65 meters, the shortest of all (five) options. · Because the bridge length is the shortest, economic efficiency of the bridge is the highest of all options.	· The bridge length is 65 meters, the shortest of all (five) options. · Although economic efficiency of the bridge is the highest of all options, the efficiency is rather low because a temporary bridge is required.	· The bridge length at the main river is 65 meters, which is the shortest of all options. · Because the bridge length is the shortest, economic efficiency of the bridge is the highest of all options.
	Road linearity and cuttings of the mountain slope	· Linearity is considered good as the current S-shaped curves can be eliminated. · No cuttings on the mountain slope at the downstream of the right-side bank are required.	· Linearity is considered bad as the current S-shape curves cannot be eliminated. · No cuttings on the mountain slope at the downstream of the right-side bank are required.	· Linearity is considered good as the current S-shape curves can be eliminated. · Although it requires cuttings on the mountain slope at the downstream of the right-side bank, the influence is smaller than that of No. 5 option. (See the above diagram.)
	Effects by the rivers and river channel improvement	· The location 15 meters upstream of the existing bridge is near the junction between the South Rukuru River and the Lura River, and will be significantly affected by bounding stones and driftwood. · Due to frequent deposition of bounding stones and driftwood near the junction, the river channel needs to be frequently improved.	· Since the location of the existing bridge is significantly deposited by bounding stones and driftwood coming from the Lura River, construction of the bridge at this location will be affected by stones and driftwood. · Due to frequent deposition of bounding stones and driftwood near the junction, the river channel needs to be frequently improved.	· Since the new bridge will be located further from the junction between the South Rukuru River and the Lura River, it will hardly be affected by bounding stones and driftwood from the Lura River. It is desirable location for constructing a bridge. · Effects of the narrow river channel are estimated to be small because the new bridge will be located further downstream of the deposition of bounding stones. However, regular improvements on the river channel will be required to secure a flow section.
	Environmental/ social considerations	· Since the access roads will pass through areas where dwellings and shops are located the most, it will require relocation of many residents. · Because there will be no parking, commercial opportunities will be lost significantly.	· Since the existing road linearity can be maintained, no resident relocation is needed. · If longitudinal surface of the access roads rises, difference between the road and the existing ground level will occur and it will be difficult to park vehicles. Therefore, commercial opportunities will be lost significantly.	· While it requires resident relocation, the number is few because of the limited number of dwellings and shops at the downstream. · Parking space can be created on the cutting area of the mountain foot and the current road.
	Implementation and maintenance management	· Since the existing bridge can be used during construction, no temporary bridge or alternative route is required. · Due to its close proximity with the junction, maintenance management such as removal of bounding stones/ driftwood and protection of bridge piers will be required.	· Since the existing bridge cannot be used during construction, a temporary bridge or bypass route is required. · Due to its close proximity with the junction, maintenance management such as removal of bounding stones and protection of bridge piers will be required.	· Since the existing bridge can be used during construction, no temporary bridge or alternative route is required. · While maintenance management such as removal of bounding stones and protection of bridge piers will be needed, because of its distance to the junction, the necessity will be minimized.
	Overall evaluation	· Because the bridge length is the shortest, economic efficiency of the bridge is the highest of all options. · Due to its very close proximity with the junction, the new bridge will be significantly affected by bounding stones and driftwood. · Many residents will be required to relocate their dwellings. Also, due to unavailability of parking, commercial opportunities will be lost significantly. △	· Although economic efficiency of the bridge is the highest of all options, the efficiency is rather low because a temporary bridge is required. · Due to its close proximity with the junction, the new bridge will be significantly affected by bounding stones and driftwood. · Although no resident relocation is required, commercial opportunities will be lost significantly. △	· Because the bridge length is the shortest, economic efficiency of the bridge is the highest of all options. · Because of the longest distance to the junction, it will hardly be any effects from bounding stones and driftwood. · While it requires resident relocation, the number is few. In addition, installation of parking lots will secure commercial opportunities. ◎

Table 2-2-6 A table comparing bridge location options (2/2)



No.4 Study Diagram

	Options	Option No.4 (25 meters upstream + channel modification of the Lura River)	No.5 (50 meters downstream)
	Option overview	・In this option, the bridge location will be shifted approx. 25 meters upstream of the existing bridge ・The option requires modification to the channel of the Lura Branch River	・In this option, the bridge location will be shifted approx. 50 meters downstream of the existing bridge ・No modification to the channel of the Lura Branch River will be required
Evaluation of options	Bridge length and economic efficiency	・The bridge length at the main river is 65 meters, and the one at the branch river is 25 meters ・Since the main river and the branch river both require a bridge respectively, economic efficiency of the bridge is the lowest of all options	・The bridge length is 70 meters, the longest of all options ・Because of the long length, it is economically inefficient
	Road linearity and cuttings of the mountain slope	・Linearity is considered good as the current S-shape curves can be eliminated ・It requires no cuttings on the mountain slope at the downstream of the right-side bank	・Linearity is considered bad as the bridge has a sequence of S-shaped curves ・Due to large cuttings on the mountain slope at the downstream of the right-side bank, the slope needs to be stabilized and planting
	Effects by the rivers and river channel improvement	・Modification of the Lura River channel will eliminate the current deposition of bounding stones and driftwood at the junction, but it will again create deposition of bounding stones and driftwood at the new junction ・Removal of bounding stones and driftwood will be needed at the new junction	・Since the new bridge will be located further from the junction between the South Rukuru River and the Lura River than the location of Option No.3, there will hardly be any effects from bounding stones and driftwood from the Lura River ・Effects of the narrow river channel are estimated to be small because the new bridge will be located further downstream of the deposition of bounding stones. However, regular improvements on the river channel will be required to secure a flow section
	Environmental/ social considerations	・Since the access roads will pass through areas where dwellings and shops are located the most, it requires relocation of many residents ・With removal of the existing residential area and installation of a large parking lot will secure commercial opportunities	・While it requires resident relocation, the number is few because of the limited number of dwellings and shops at the downstream ・Parking space can be created on the cutting area of the mountain foot and the current road
	Implementation and maintenance management	・Since the existing bridge can be used during construction, no temporary bridge or alternative route is required ・Removal of bounding stones will be needed at the new junction ・Maintenance management of new bridges built on the South Rukuru River and the Lura River will be required	・Since the existing bridge can be used during construction, no temporary bridge or alternative route is required ・While maintenance management such as removal of bounding stones and protection of bridge piers will be needed, because of its distance to the junction, the necessity will be minimized
	Overall evaluation	・Due to costs associated with the channel modification in addition to construction of the two bridges, its economic efficiency is the lowest of all options ・There will be no effects from bounding stones and driftwood, but due to effects of backwater the water level will rise in time of flooding ・While it requires relocation of many residents, installation of a large parking lot will secure commercial opportunities △	・Due to the long bridge length, economic efficiency of the bridge is low ・Because of the longest distance to the junction, it will hardly be any effects from bounding stones and driftwood ・While it requires resident relocation, the number is few ・Installation of parking lots will secure commercial opportunities ○

(2) The second comparison of different bridge locations

1) A result of selection from the first group of bridge location options

As a result of the first comparison of five bridge location options, Option No.3 (25 m of the downstream) was selected as the most desirable option for the following reasons;

① Because its bridge length is the shortest, the cost of bridge construction is expected to become the most economical among all options.

② Since the current bridge and route can be used, a temporary bridge and an alternative route will not be needed for construction.

③ Effects from bounding stones and driftwood are less than those of other options.

④ The number of resident relocation and removal of dwellings is estimated to be minimum.

However, an in-depth field survey conducted under this pilot study revealed problems of Option No.3 as shown in the section below.

2) Option No.3 problems

Problems of Option No. 3 are as follows;

① In the initial horizontal alignment which curve lines are depicted on the bridge side, using prestressed concrete post-tension girders for a curved bridge is difficult in terms of technical feasibility and implementation. (Fig. 2-2-6)

② Hence, straight lines need to be depicted in the horizontal alignment. On the other hand, building a straight bridge at 25 meters downstream will necessitate more cuttings on the slope of the mountain foot at the Muzuzu side, and will make the bridge length longer towards Karonga than that of the initial plan (Fig. 2-2-7).

③ Adjusting the bridge location as close as 20 meters downstream will necessitate more cuttings on the slope of the mountain foot if the bridge is placed in parallel with the current bridge location (Fig. 2-2-8).

④ Adjusting the bridge location as close as 15 meters downstream will still necessitate more cuttings on the slope of the mountain foot if the bridge is placed in parallel with the current bridge location (Fig. 2-2-9)

3) Selecting a final bridge location

Given the problems of Option No.3 shown in the previous section 2), the following “Revision of Option No.3” was finally selected as a bridge location option that solves these problems (Fig. 2-2-10)

① In order to reduce cuttings on the slope of the mountain foot at the Muzuzu side and to shorten the bridge length at the Karonga side, the new bridge will be built diagonally to the existing bridge.

② To this end, Abutment A1 will be built 16 meters downstream of the existing Rukuru Bridge, and Abutment A2 will be built 19 meters downstream.

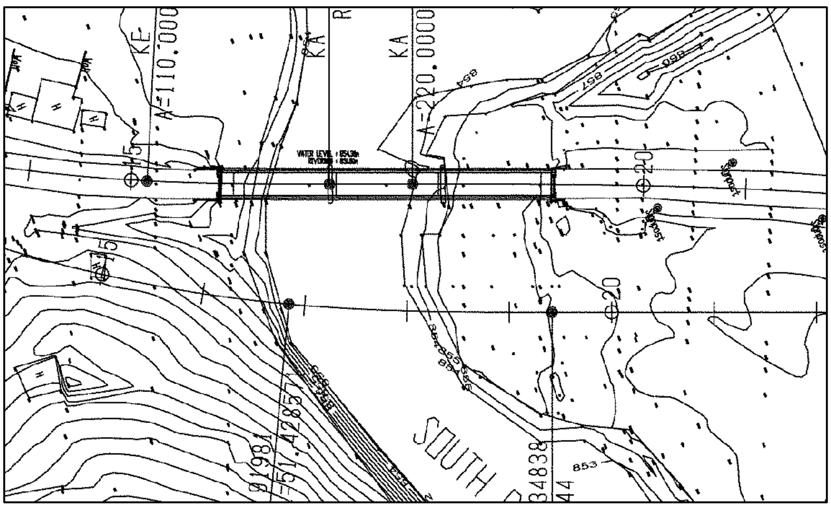


Fig. 2-2-6 Option No.3 (Initial plan)

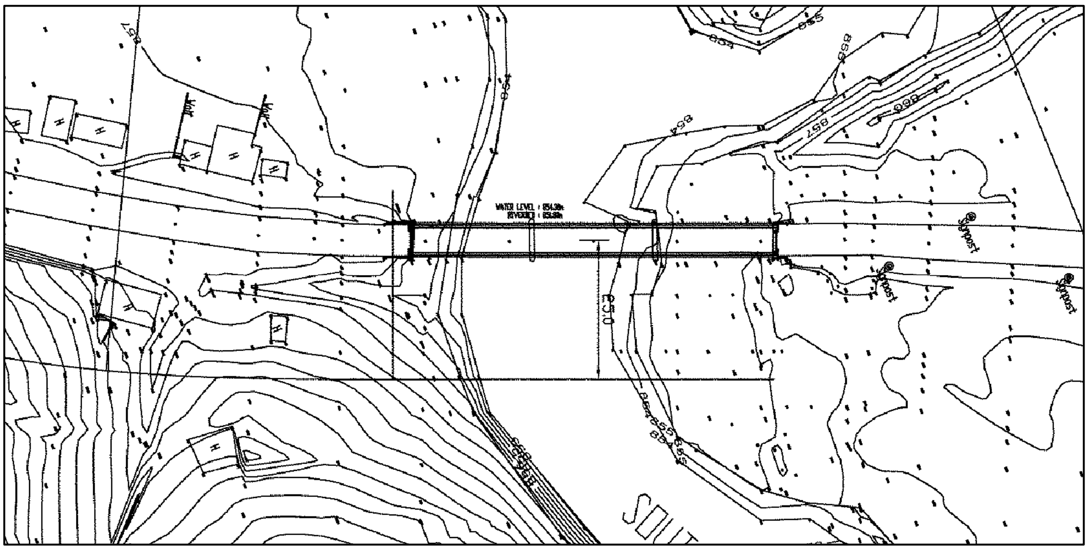


Fig. 2-2-7 Straight Bridge Option 1 (25m parallel distance)

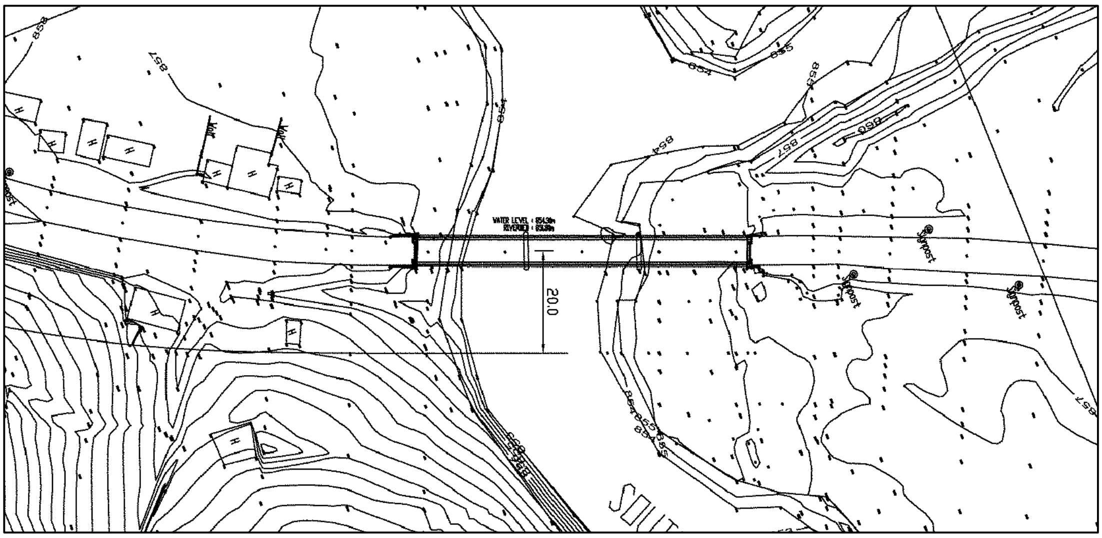


Fig. 2-2-8 Straight Bridge Option 2 (20m parallel distance)

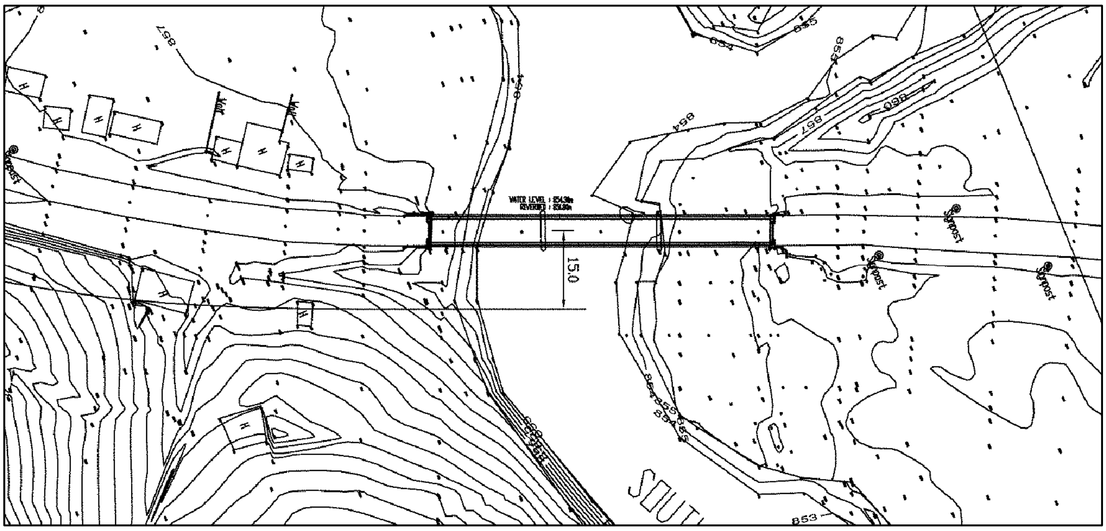


Fig. 2-2-9 Straight Bridge Option 3 (15m parallel distance)

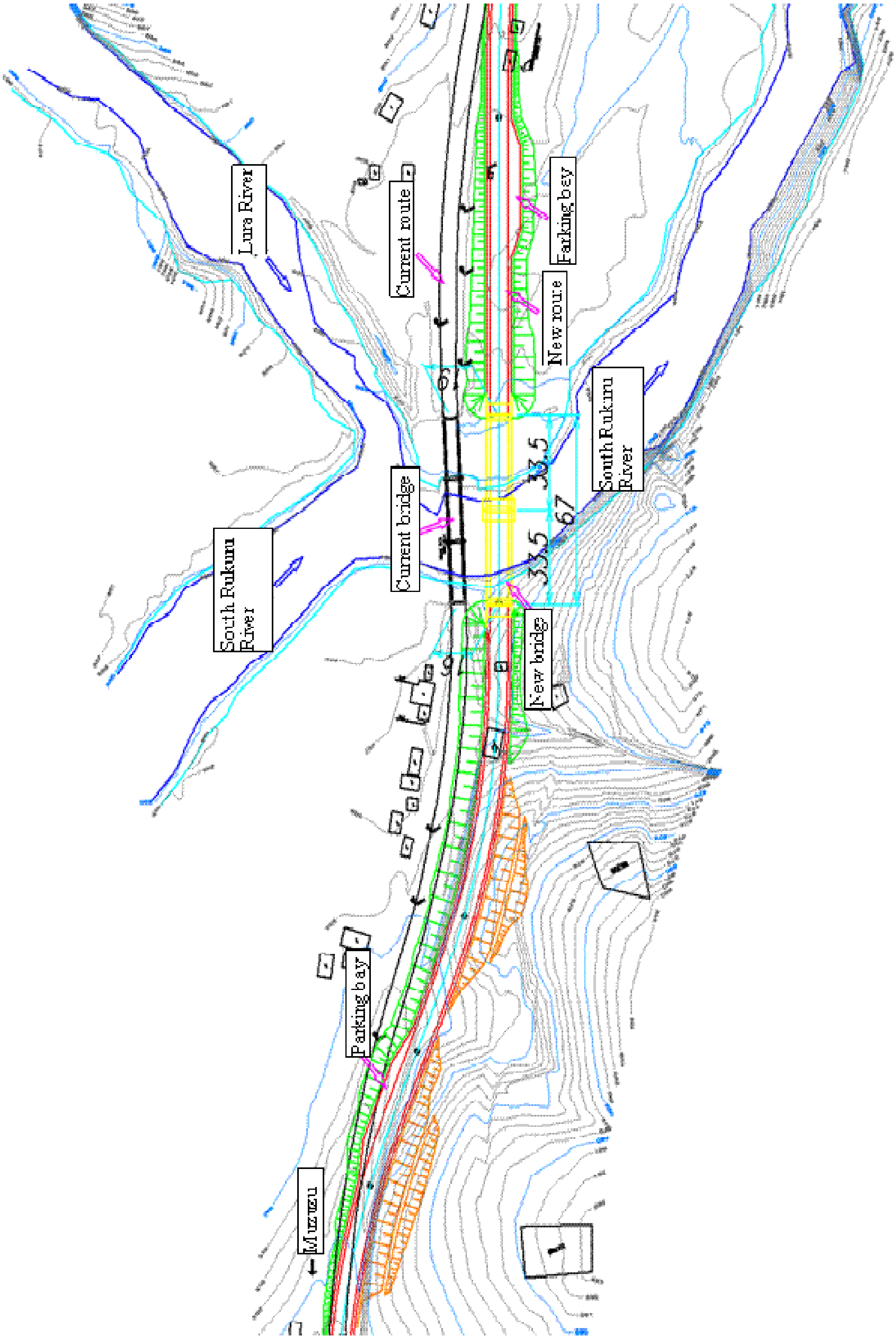


Fig. 2-2-10 Plain View of the Finally Selected Bridge Location

2-2-2-5 Profile Plan of the Bridge and Roads

The project cost for bridge construction largely depends on the vertical height of the bridge including its access road. When a bridge passes through a river, its vertical alignment is, in general, determined by the design high water level, and the lower the level the more economical the project cost becomes. In the case of the South Rukuru Bridge, the road and the bridge are said to be flooded due to heavy rain during the rainy season. Hence, the vertical alignment of the bridge and its access road must take into account the water level in time of flooding, apart from the design high water level (HWL).

(1) Selecting vertical alignment options

The design high water level (HWL) of the bridge will be studied and calculated based on results of the hydraulic/ hydrological analysis. With regard to the water level in the past flood events, it was learned from the study of the existing data and on-site interviews that floods occurring every year usually last a short period of time though, in some cases, submerge the timber deck of the Rukuru Bridge. It was also learned that, during the period between 2003 and 2006, the largest flood on record covered the upper part of the parapet of the existing bridge (approx. 80 cm from the deck.) The result of the preliminary survey conducted in 2008 indicated the necessity for embankment of at least 2.5 meters for the new bridge and its access road, and the preliminary study report indicated that "in the requirement document, it was requested that the bank of the bridge and access road be raised by one to two meters to prevent them from being covered with water in time of flooding."

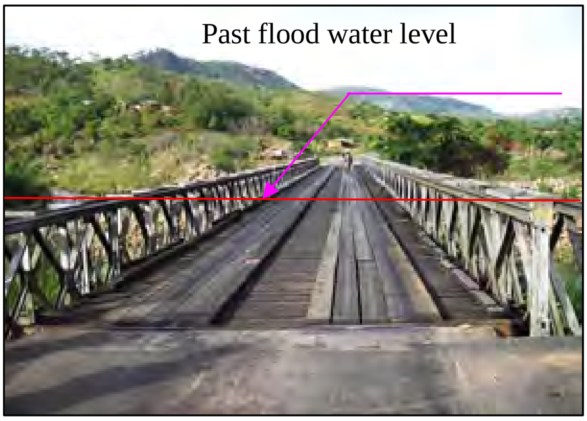


Photo 2-2-1 Past Flood Water Level of the Existing Rukuru Bridge

Photo 2-2-2 The Existing Rukuru Bridge Damaged by Flood

Based on these circumstances, the following three options were selected for vertical alignment of the South Rukuru Bridge and its access road;

- Option 1 (The current road height);
  Aligning the height of the new bridge with the road height of the existing Rukuru Bridge.
- Option 2 (A 1-meter raising);
  Raising the height of the new bridge by one meter from the road height of the existing Rukuru Bridge.
- Option 3 (A 2-meter raising);
  Raising the height of the new bridge by two meters from the road height of the existing Rukuru Bridge.

(2) Studying design high water level

1) Defining planned cross section

The planned cross section at the bridge location should take into account conditions at the upstream as well as at the junction with the branch river to ensure the secure flow of the design flood discharge.

Since the planned cross section at the bridge construction location depends on the flow capacity of the downstream river channel, its insufficient flow capacity will result in an increase in the water level. Hence, the planned cross section at the bridge location should be first defined for the planned cross section at the downstream and the channel cross section at the bridge construction location.

On either side of the banks at the planned cross section, revetments will be set at a gradient of 1.1.0 for bank protection at the abutments and for the safe ground behind the river channel. Provided that the flow velocity in front of the revetments in time of flooding is expected to be more than five meters per second, mortared masonry using cobbled stones will be adopted for revetments.

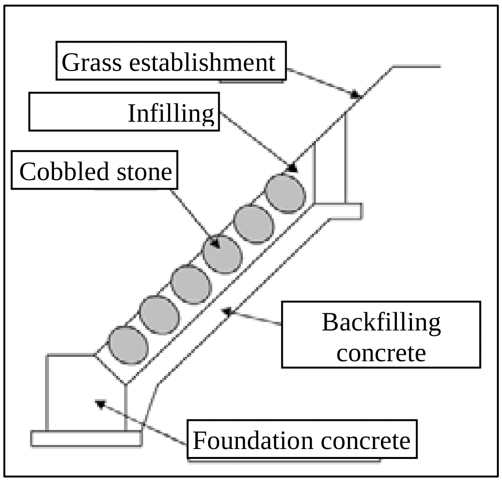


Fig. 2-2-11 Revetment Type

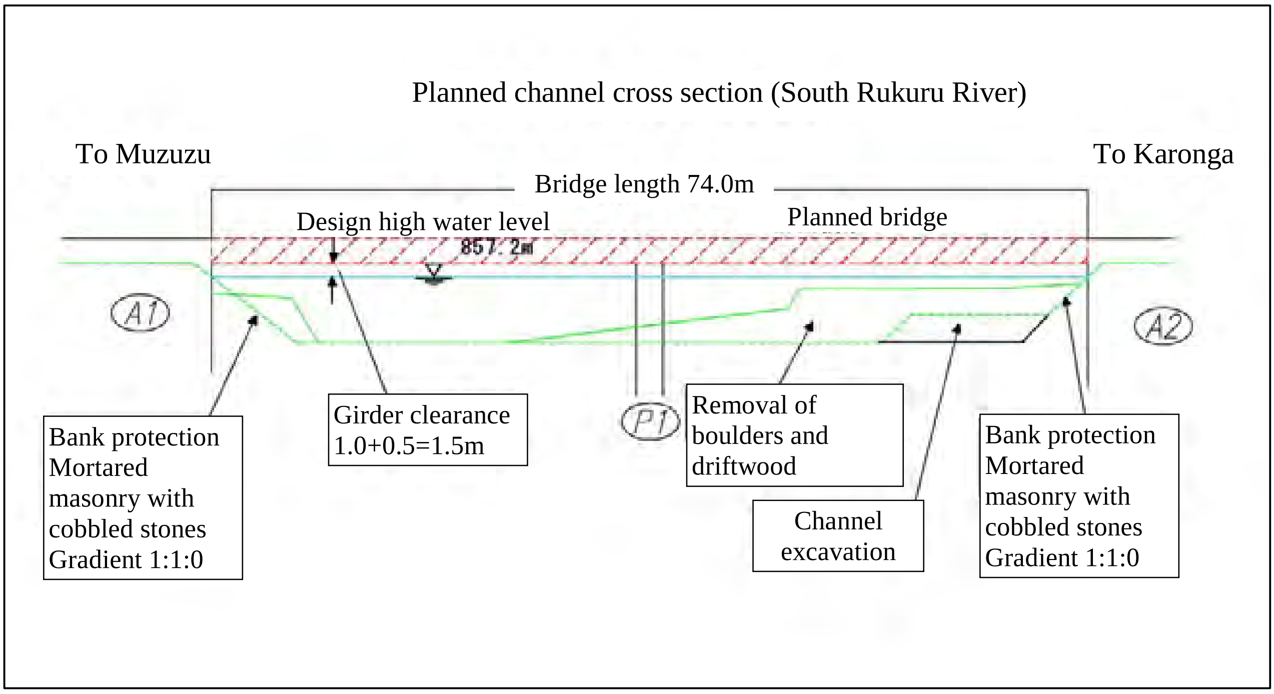


Fig. 2-2-12 Planned River Channel Cross Section (at the bridge location)

1) Case studies

Design high water level is determined through definition of the planned cross section at the bridge location and study on the downstream channel cross section. For this, the following cases were studied. Its calculation adopted non-uniform flow calculation.

① Case 1: Creating a left bank revetment on the current cross section.
② Case 2: Excavating the river channel cross section on the left bank of the current cross section

to increase the river bed width to approximately 50 meters.

③ Case 3: Excavating the river channel cross section on the left bank of the current cross section to increase the river bed width to approximately 45 to 50 meters.

2) Study result

① Case 1

Due to the insufficient flow capacity at the current cross section of the downstream river, the design high water level at the bridge location is set as 859 meters, one meter above the deck height of the existing Rukuru Bridge. Hence, the cross section of the downstream river channel needs to be excavated to secure the flow capacity.

② Case 2

It was understood that with an increase of the river bed width to 50 meters as a result of excavation of the left bank of the channel cross section, the design high water level of the bridge location would be set as 856.9 meters, one meter below the deck height at the existing Rukuru bridge. However, the bridge length of the original plan (67.5m) is not able to secure enough width of the river bed at the downstream of the bridge location, the length of the bridge needs to be 74 meters, and the river bed should be 45 meter-wide, in consideration of its feasibility.

③ Case 3

From the cross section planning of the downstream channel (bed with 45 to 50 meters) based on the 74-meter bridge length, the design high water level at the bridge location is estimated to be 857.2 meters, approximately 0.8 meters below the deck height of the existing Rukuru Bridge. A water level increase with bridge abutments is estimated to be 0.3 meters.

3) Considerations and conditions for planning

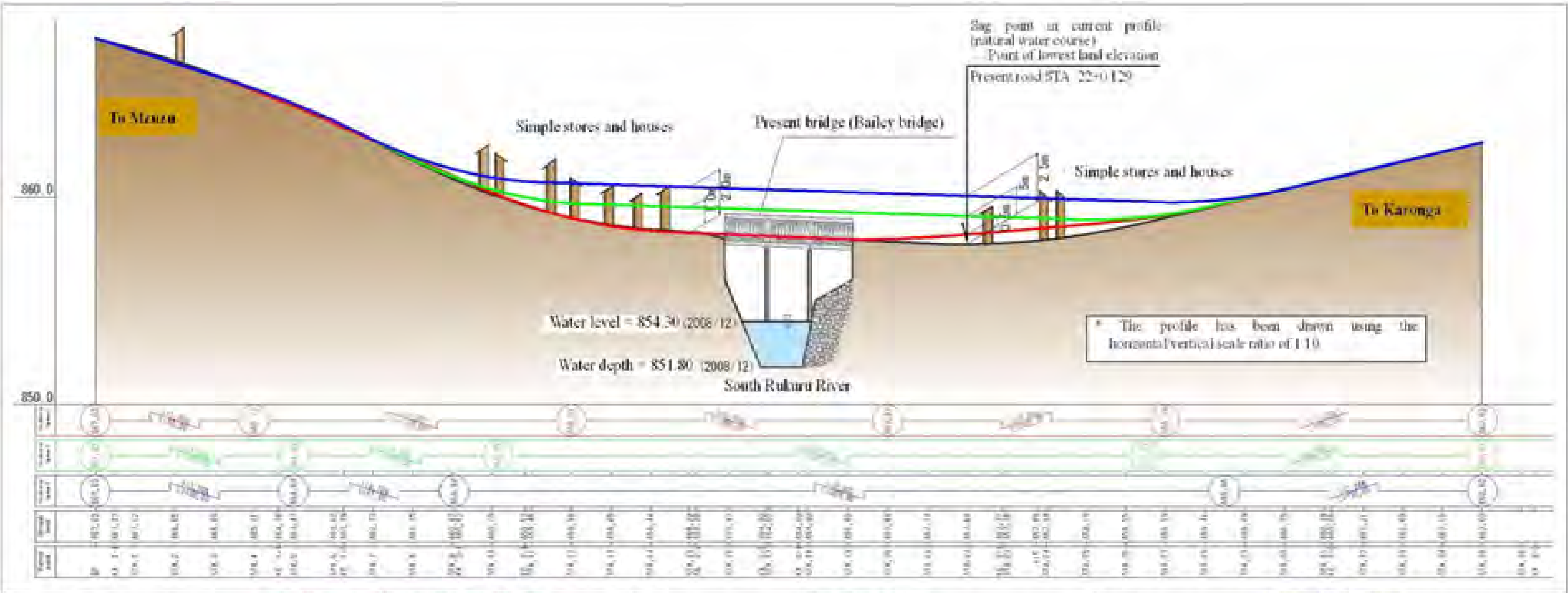
The following considerations need to be taken into account for river planning

- The current cross section at the downstream needs to be retained due to imposing cliffs at the right bank and exposed rocks at the foundation.
- From the geological survey, the depth of the rocks is 849 meters, lower than the 851.8 meter-high river bed at the current bridge location.
- Because of the deposition of sand gravel on the left bank, excavation of the channel cross section at the left bank is possible.

(3) Comparison of vertical alignment options

Table 2-2-7 shows a result of comparison among three options selected for vertical alignment.

Table 2-2-7 Comparison of Road Profile Options



Options		Option 1 (same road level as the present bridge)	Option 2 (1 m raising)	Option 3 (2 m raising)
Summary of options		· In this option, the profile of the new bridge will be the same as the road surface level of the present bridge · The access road on the northern bank will need filling of up to 0.5 m over present ground. · Plan alignment is assumed to follow modified Option No. 3	· In this option, the profile of the new bridge will be 1 m higher than the road surface level of the present bridge. · The access road on the northern bank will need filling of up to 1.5 m over present ground. · Plan alignment is assumed to follow modified Option No. 3	· In this option, the profile of the new bridge will be 2 m higher than the road surface level of the present bridge · The access road on the northern bank will need filling of up to 2.5 m over present ground. · Plan alignment is assumed to follow modified Option No. 3
Evaluation of Options	Necessary height of new bridge	The necessary height of new bridge (road surface level) is 3 m (2 m height of new bridge structure + 1 m safety margin) above the flood water level		
	Impact of floods	· There is a risk of driftwood hitting the new bridge during floods reaching 3 m below the road surface level of the present bridge (several times in a year)	· There is a risk of driftwood hitting the new bridge during floods reaching 2 m below the road surface level of the present bridge (estimated to occur once in 10-20 years)	· There is no risk of driftwood hitting the new bridge, if sufficient flow cross-section is secured to keep floods from reaching 1 m below the road surface level of the present bridge
	Profile linearity	· The filling in the low grounds along the access road on the northern bank will achieve gentler vertical alignment and better profile linearity	· The 1 m additional filling over Option 1 will smoothen the otherwise low overall profile and achieve better profile linearity than Option 1	· The 2 m additional filling over Option 1 will smoothen the otherwise low overall profile and achieve considerably better profile linearity
	Impact of filling	· The filling in the low grounds along the access road on the northern bank will be about 0.5 m at maximum over present ground, and have little impact on surrounding areas · No filling will be required along the access road on the south bank	· The filling in the low ground along the access road on the northern bank will be about 1.5 m at maximum over present land, and have limited impact on surrounding areas · The filling in the mountainous area along the access road on the southern bank will be about 1 m at maximum over present ground, and have little impact on surrounding areas	· The filling in the low grounds along the access road on the northern bank will be about 2.5 m at maximum over present ground, but the impact will be small because the area is a farmland · The filling in the mountainous area along the access road on the southern bank will be about 2 m at maximum over present ground, but the impact on surrounding areas will be minimized by a shift of alignment
	Environmental and social considerations	· The access road on the northern bank will have a small level difference from present ground, but construction of a parking zone is possible · The access road on the southern bank will be the same level as present ground, and the construction of a parking zone is possible	· The access road on the northern bank will have a level difference of 1.0-1.5 m from present ground, but construction of a parking zone is possible because the area is a farmland · The access road on the southern bank will have a level difference of up to 1 m from present ground, but the extent of its impact will be limited and the construction of a parking zone is possible	· Although the access road on the northern bank will have a level difference of 2.0-2.5 m from present ground, construction of a parking zone is possible because the area is a farmland · Although the access road on the southern bank will have a level difference of up to 2 m from present ground, it is possible to construct a parking zone at a location with low filling height
	Economy	· Due to the lowest profile, cost performance is the highest among the 3 options	· Due to the profile higher than Option 1, cost performance is ranked between the other 2 options	· Due to the highest profile, cost performance is the lowest among the 3 options
	Overall evaluation	· There is a risk of driftwood hitting the new bridge several times a year · The impact of filling on surrounding areas is minimal · Construction of parking zones along the access road is possible · Cost performance is the highest among the 3 options △	· There is a risk of driftwood hitting the new bridge once in 10-20 years · The impact of filling on surrounding areas is limited · Construction of parking zones along the access road is possible · Cost performance is ranked between the other 2 options ○	· There is no risk of driftwood hitting the new bridge, provided sufficient flow cross-section · The impact of filling on surrounding areas is limited · Construction of parking zones along the access road is possible · Cost performance is the lowest among the 3 options, but flood proofing performance is the best ◎

(4) Considerations for freeboard (0.5 meters)

Taking into consideration a temporary water increase due to wave in time of flooding, swell, hydraulic jump and driftwood etc., the bank revetment height needs to have a certain clearance. Since the design flood discharge (Q) of the South Rukuru River is ranging from 500 or above to 2000, as shown in the table below, a 1.0 meter clearance is required.

Table 2-2-8 Design Flood Discharge and Corresponding Freeboard
(design standards for river maintenance facilities etc.)

Item	1	2	3	4	5	6
Design flood discharge m^3/s	Below 200	200 or above, below 500	500 or above, below 2,000	2,000 or above, below 5,000	5,000 or above, below 10,000	10,000 or above
Freeboard meter	0.6	0.8	1.0	1.2	1.5	2.0

On the other hand, for ordinary rivers, the above freeboard correspondingly applies to girder clearance. However, when the above freeboard is considered an obstacle to discharge at a river that has a large amount of driftwood, the girder height needs to be increased as required. In addition, “Guideline (proposal) for bridge installation at rivers within designated erosion control areas” also defines the freeboard to be 0.5 meters.

For the South Rukuru River, in consideration of the large amount of driftwood falling in time of flooding and the necessity for erosion control to handle falling trees caused by a mountainside collapse due to the steepness of the mountain slope at the downstream basin, the 0.5m freeboard used in erosion control areas should be added to the standard clearance.

Hence, the girder clearance (freeboard) of the South Rukuru Bridge shall be set as 1.0m＋0.5m＝1.5m, and with the addition of 0.5m to the 2.0-meter height raise selected from Table 2-2-8, Comparison of vertical alignment options, the final height raise shall be defined as 2.5 meters.

2-2-2-6 Creating of Lay-bys

After the replacement of the bridge, the road will have 2 lanes and the humps at the both ends of the existing bridge will be removed, eliminating the need for vehicles to slow down or stop at the ends of the bridge and thereby spoiling the commercial opportunities for the small stores at the foot of the existing bridge. For the sake of environmental and social considerations, MOTPI and RA desire to have lay-bys near the access roads so that the commercial opportunities of these small stores may be ensured.

It is desirable to create a lay-by along the up line and one along the down line. These will be located near the present commercial establishments on the Mzuzu side and making use of a farm field on the Karonga side

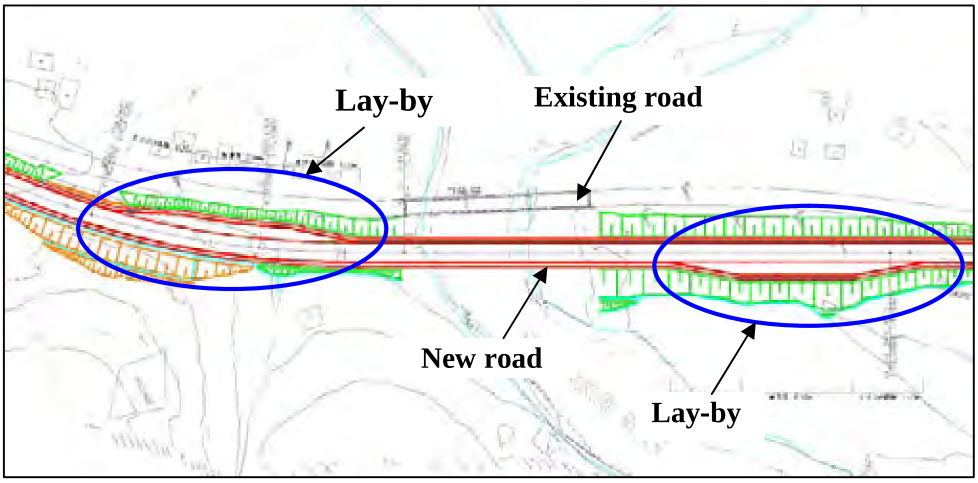


Fig. 2-2-13 Lay-by Layout

2-2-2-7 Studying Modification of the Lura River Channel

(1) Purpose of channel modification

The preliminary study proposed modification of the Lura Branch River channel for the following purposes;

① To relocate the junction between the South Rukuru Bridge and the Lura Bridge to downstream of the new bridge location to solve problems associated with the deposition of boulders and driftwood.

② To move the junction downstream to improve the flexibility of bridge positioning.

(2) Options for comparison

1) The channel modification option

This option is to modify the Lura River channel from the position approximately 100 kilometers upstream of the junction and to artificially create a new channel to move the meeting point between the Lura River and the South Rukuru River to 260 meters downstream of the existing Rukuru Bridge.

Planning under this option needs to consider the followings;

① For planning of a new artificial channel, safe flow of flood water must be secured for many years.

② Planning of the channel and the facility size must also take into to account flow of the entire flood water at the Lura River without overflow in the channel.

2) The status quo option

This option is to keep the status quo at the Lura River and to clear boulders accumulated on the left bank at the current bridge location in parallel with the bridge construction. After completion of the new bridge, maintenance and management of the Rukuru River and the Lura River will be conducted. Maintenance and Management include dredging of sediments on the channels of the main river and the branch river, bank protection and channel improvement as measures to secure the flow capacity of the channels.

(3) The current situation on sediments

Boulders and driftwood transferred due to the past flooding and mudslides are accumulated on the left bank of the junction between the South Rukuru River and the Lura River. Sediments are found in a 70 meter-long section, which starts 20 meters upstream of the junction with the branch river and ends 50 meters downstream of the current bridge. The sediments occupy one third to one half of the river width. The space under the girder between A2 to P2 is only 1.5 meters, and most of the space is virtually blocked.

(4) Comparison result

As a result of the comparison between two options; the status quo option and the channel modification option, the status quo option was considered more desirable than the modification option from the following reasons; (Table 2-2-9)

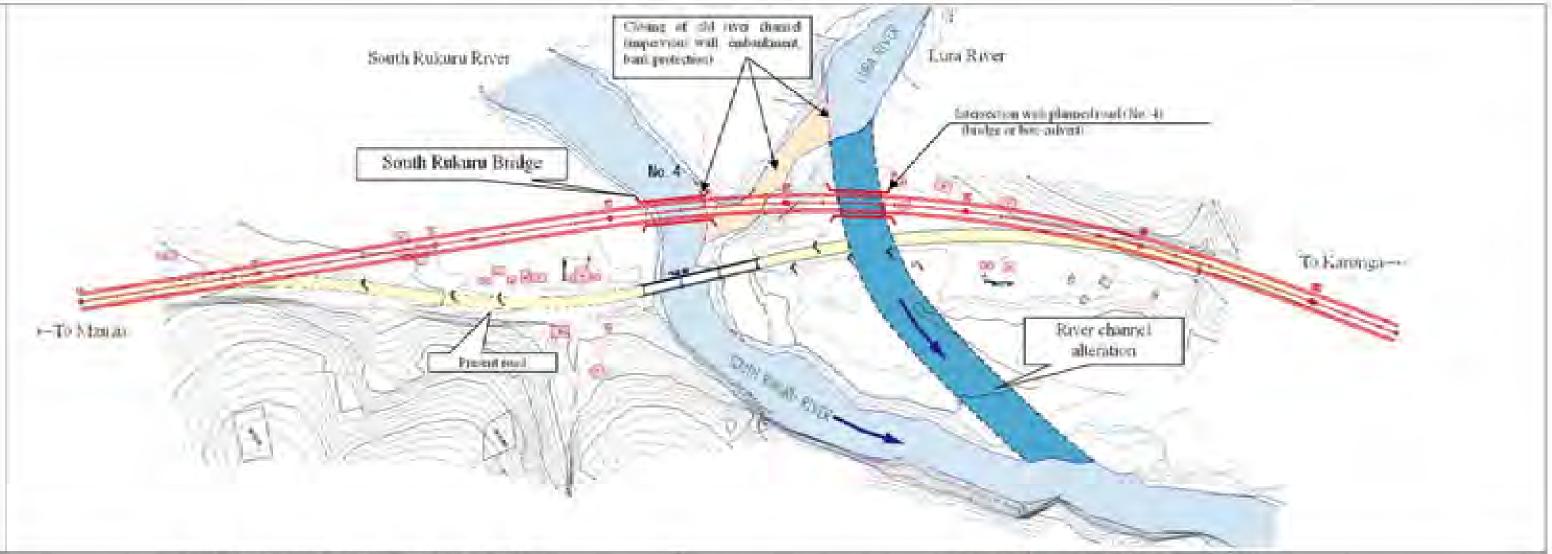
① Modification of the Lura River channel requires construction of a new bridge, which will pass through the Lura River, apart from the South Rukuru Bridge.

② With the necessity of modification, the cost will be added to the bridge construction cost, and the total construction cost will increase significantly.

③ Since artificial modification of the naturally flowing river channel requires large-scale work, incorporating it into the scope of the bridge replacement will be extremely difficult.

④ It is difficult to hold back water overflowing from the Lura River in time of flooding. The work defined in the project scope is only to set vertical height of the bridge to protect the new bridge and the access road from overflowing water, and to allow immediate discharge of overflowing water.

Table 2-2-9 Comparison for Modification of the Lura River Channel

Map of key features			
Options		Option 1: Preservation of Present Lura River Channel	Option 2: Alteration of Lura River Channel
Summary of options		・In this option, the tributary Lura River will be left as it is without modification to its river channel	・In this option, the river channel of the Lura River will be altered so that it will join the South Rukuru River at about 200 m downstream from the present bridge
Evaluation of options	Condition of the Lura River and the extent of river channel alteration	・In the segment upstream from the confluence, the entire river width (30-50 m) is filled with boulder and driftwood depositions that have been carried by floods. The gradient down to the confluence is about 1:40 to 1:50	・The flood plain on the left bank of the Rukuru River will be excavated to create a new river channel with the width of about 30 m ・The old river channel from diversion point to confluence will be closed using an impervious wall and embankment
	Impact on the South Rukuru River	・Boulders and driftwood will deposit near the confluence and within the river channel of the Lura River	・Boulders and driftwood will deposit near the new confluence and within the altered river channe
	Impact on river environment	・There will be no notable problems	・Because the route of the Lura river will be changed, local environment including fish, bottom fauna, and vegetation will be affected
	Impact on bridge plan	・If a bridge location nearer to the confluence is chosen, substructure will be affected by the deposition and hitting of boulders from the Lura River ・Bridge location needs to be selected to minimize the impact of boulders and driftwood	・Because the present confluence point will be removed, current restrictions due to the deposition and hitting of boulders and driftwood will be eliminated ・A bridge will be needed at the crossing of the Main Road
	Impact on road plan	・There is no elements causing restrictions in planning	・Depending on the longitudinal profile of the altered river bed, the height of the intersection with the Main Road may cause restrictions
	Environmental and social considerations	・Because the present condition will be preserved, no relocation of inhabitants will be needed ・Depending on the scale of floods, inundation may occur in the segments upstream and downstream from the embankment on the left bank of the Lura river and cross the Main Road	・There are houses and stores near the route of the altered river channel, and relocation of inhabitants will be needed ・Inundation may occur when a debris flow causes massive and quick deposition within the altered river channel
	Work performance and maintenance	・No detour and temporary bridge will be needed during construction works ・Removal of boulders and driftwood in the confluence area will be needed ・The problem of deposition due to soil supply from the upstream segment of the Lura River needs to be resolved separately	・Because the river crosses the Main Road, a detour and a temporary bridge will be needed during river channel alteration works ・Removal of boulders and driftwood will be needed inevitably when deposition has occurred within the altered river channel ・The problem of deposition due to soil supply from the upstream segment of the Lura River needs to be resolved separately
	Effect on the flooding of the Lura River and countermeasures	・Because erosion control measures in upstream areas is insufficient, soil supply is expected to continue in the future ・Because the height of embankment is insufficient, even small floods are likely to cause inundation ・The placement of the culvert under the raised road will enable draining of floodwater in the case of inundation	・Because erosion control measures in upstream areas is insufficient, soil supply is expected to continue in the future ・Because the height of embankment is insufficient, even small floods are likely to cause inundation ・Inundation within the altered river channel should be prevented by widening of the river channel to increase the flow carrying capacity
	Overall evaluation	・This option is considerably more economical than Option 2, because only the cost for the construction of South Rukuru Bridge is involved ・This option requires the solution of the problems at the confluence and the problem of inundation from the Lura River ・The problem of deposition due to soil supply from the upstream segment of the Lura River needs to be resolved separately ○	・This option is considerably less economical than Option 1, because it requires a bridge to cross the Main Road in addition to South Rukuru Bridge, as well as river channel alteration works ・The problems at the present confluence will be resolved, but problems such a deposition of boulders in the new confluence area will emerge ・Because river channel alteration alone does not resolve the problem of deposition due to soil supply from upstream areas, this problem needs to be resolved separately ×

2-2-2-8 The Overall Plan

(1) Design standards/ requirements for the project

1) Road design requirements

The bridge road design will comply with the standard established in Malawi and the standard established by the South Africa Transport and Communications Commission (the SATCC standard,) and areas not covered by the standard will follow the Japanese standard (Government Order on Road Design Standards.) Table 2-2-6 shows requirements for the road design.

Table 2-2-10 Road Design Requirements

Items	Malawi standard	SATCC	Japanese standard	**Standard for the project**
Road type	Highway （National road）	Highway （National road）	General national road	**Highway (National road)**
Terrain type (Flatland/ hill/ mountain)	Mountain	Mountain	Mountain	**Mountain**
Design speed (km/h)	80	80	80	**80**
Design vehicle	WB-15	WB-15	Semi trailer	**WB-15**
Lane width(m)	3.35 x 2	(3.1-3.7)×2	3.5 × 2	**(3.35+0.3)×2**
Shoulder width （Outward）(m)	-	1.0	1.75	**1.2**
Maximum vertical gradient	5.0	5.0	4.0	**3.0**
Maximum super elevation (%)	10.0	10.0	10.0	**9.0**
Maximum cross fall (%)	2.5	2.0	2.0	**2.5**
Stopping sight distance (m)	115	115	110	**115**
Minimum horizontal curve radius (Absolute value)（m)	210	210	230-280	**280**
Minimum vertical curve radius 凸 K value	32	33	-	**-**
Minimum vertical curve radius 凸 (m)	-	-	3,000	**7,800**
Minimum vertical curve radius 凹 K value	25	25	-	**-**
Minimum vertical curve radius 凹 (m)	-	-	2,000	**3,000**
Minimum relaxation curve parameter (A value)（m)	-	-	140	**120**
Minimum relaxation curve length (m)	42.8	42.8	70	**51.4**

2) Bridge design requirements

i) Hydraulic requirements

a) Probabilities

Based on the design scale and lifetime of the bridges in the past grant aid projects, 50 year probabilities were estimated.

b) Design flood discharge

From the design flood discharge in 2-1-2 5), the 50-year probability of the design flood discharge is 1,200 cum/s.

c) Design high water level

From the study results in 2-2-5 (2) 3), the design high water level is 857.2 meters.

d) Scour depth

Height of the bridge pier foundation is determined in consideration of scour of the bridge piers. As a result of the study, the scour depth is estimated to be 3.0 meter high at the bridge piers. Hence, the space for bridge pier footings under this project should be secured more than the scour depth, and footings will be buried into rock beds.

For A1 and A2 abutments (direct foundation,) the footing bottom should be sufficiently buried in a good supporting layer such as rock beds.

e) Bank protection

Installation of bank protection was studied based on calculation of scour of the bridge abutments and piers. Based on the result, measures taken in time of scour, including deepening of the foundations and protection of river banks and abutments through bank protection and foot protection, are adopted. For bank protection, mortared masonry is adopted as a method in consideration for its high resilience to collapses and adaptability to flow velocity.

Under the scope of bank protection at the left bank abutment, revetments will be built as foundations for road embankment, and, to secure the foundations, mortared masonry banks are installed around the required perimeter. Specifically, mortared masonry banks were installed in sequence at the left bank within the area of the junction with the Lura River. For bank protection of the right bank abutment, mortared masonry banks are installed around the perimeter of excavation conducted under the abutment construction, in consideration of steep cliffs at the downstream.

For the front face of the abutment and the upstream, mortared masonry banks are installed around the perimeter required at the upstream to secure foundations for road embankment and to allow smooth water flow in time of flooding.

Bed protection works are put in place in front of the bank protection as a countermeasure for scour of the bank protection foundation works. Bed protection works use cobblestones available at the site as concrete blocks, which will be created and installed on site. The height of bank protection is defined as HWL + 1.0m, and the ground height near the abutments is 868.2 meters high. Also, the current foundations and wire mats are used and filled to secure smooth flow in time of flooding and to prevent damage caused by water running from the edge of the bank.

ii) Design live load

For live load, B live load specified in the Japanese standard (Japanese road/ bridge manuals) was adopted for the following reasons;

① The below bending moment comparison between HB load specified in BS and B live load specified in the Japanese standard showed no significant difference between the two, but B live load presented a slightly higher bending moment than that of the other load (see Fig. 2-2-11.)
② Hence, it is better to adopt Japan’s B live load for the design to be on the safe side.
③ The past Japanese grant aid projects including the Bakili Muluzi Bridge, the Lwazi Bridge and the Nankokwe Bridge adopted Japan’s B live load.
④ Bridges adopting Japan’s B live load have enough strength, which has kept them reliable.

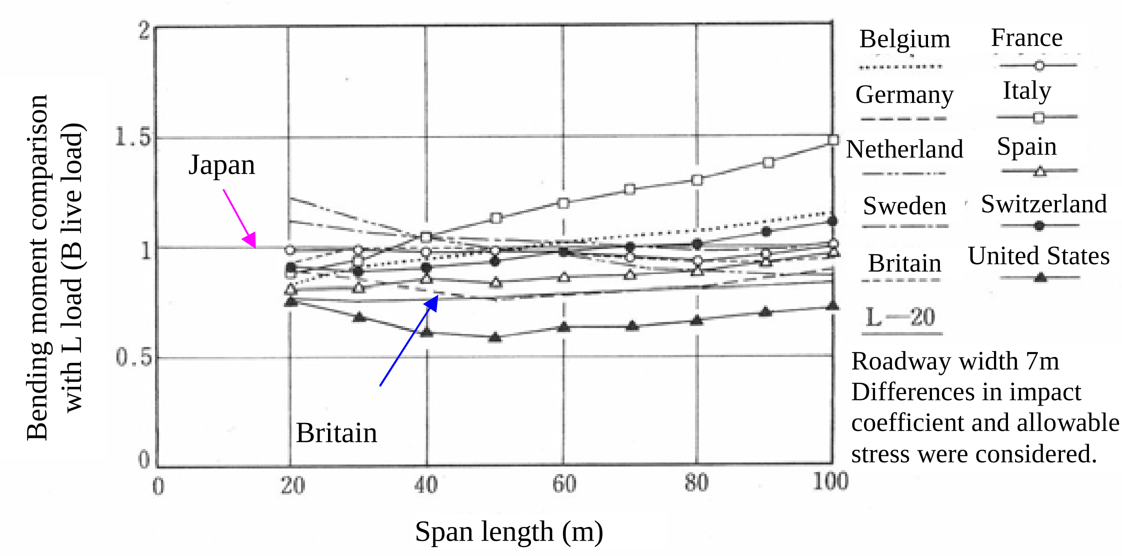


Fig. 2-2-14 Comparison of Design Bending Moments of Live Loads by Country

iii) Seismic load

a) Seismic study

Fig. 2-2-15 shows seismic distribution in Malawi during the period between 1901 and 2007. Also, acceleration distribution of earthquakes that occurred in Malawi for the South Rukuru Bridge is shown in Fig. 2-2-16. Fig. 2-2-17 to Fig. 2-2-19show acceleration distribution for the Bakili Muluzi Bridge (the Mangochi Bridge), the Lwazi Bridge and the Nankokwe Bridge built under the Japanese grant aid projects for Malawi.

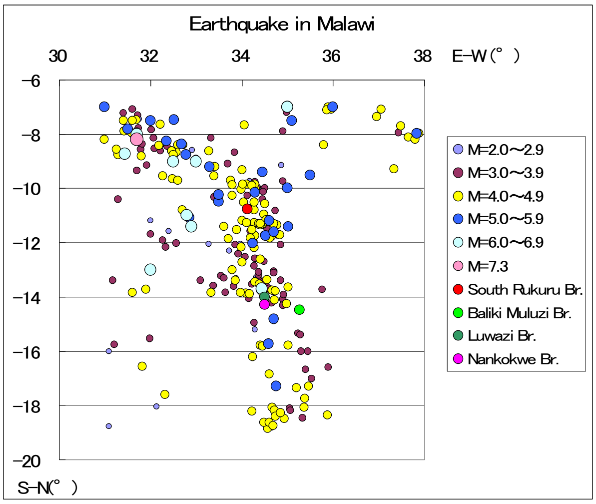


Fig. 2-2-15 Seismic Distribution in Malawi

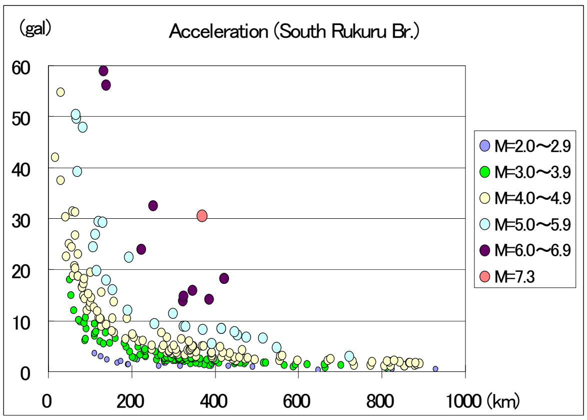


Fig. 2-2-16 Acceleration Distribution for the South Rukuru Bridge

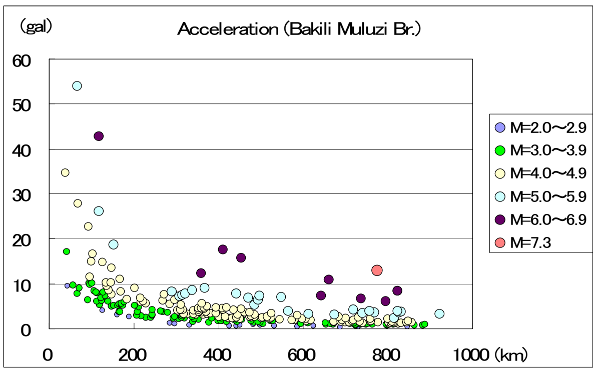


Fig. 2-2-17Acceleration Distribution for the Bakili Muluzi Bridge

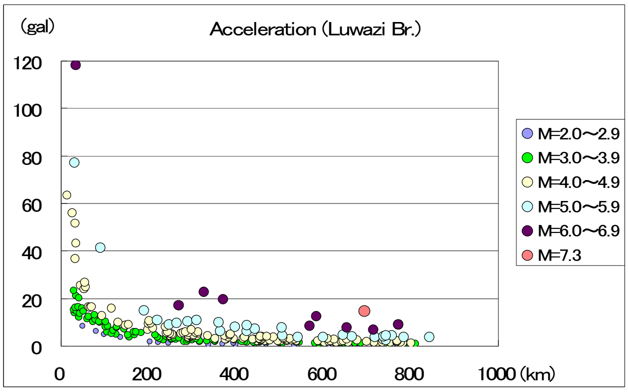


Fig. 2-2-18 Acceleration Distribution for the Lwazi Bridge

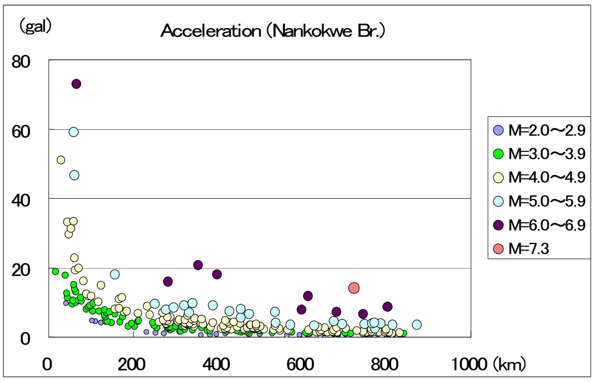


Fig. 2-2-19 Acceleration Distribution for the Nankokwe Bridge

b) Seismic load

A design horizontal seismic coefficient under this outline design was defined as 0.10 for the following reasons (see 2-2-8(1)2)iii)a) Seismic study);

① There has been no large earthquake in the periphery of the concerned bridge (see Fig. 2-2-15-Fig. 2-2-16.)

② Acceleration of earthquakes detected in the periphery of the concerned bridge is 60gal or below (see Fig. 2-2-16.)

③ Bridges built in the past Japanese grant aid projects, including the Bakili Muluzi Bridge, the Lwazi Bridge and the Nankokwe Bridge also adopted Kh=0.10 (see Fig. 2-2-17-Fig. 2-2-19)

iv) Material strength

Strength of materials used under this project is as follows;

① Design standard strength of concrete for prestressed concrete superstructure

Design standard strength for concrete used for prestressed concrete superstructure is $\sigma ck = 40 N/mm^2$.

② Design standard strength of reinforced concrete

Design standard strength for reinforced concrete used as reinforced concrete materials for the substructure works, foundation, wheel guard and wall rail is $\sigma ck = 24\ N/mm^{2.}$

③ Design standard strength of plain concrete

Design standard strength for concrete used as plain concrete materials used for concrete leveling and filling for the walkway is $\sigma ck = 18\ N/mm^2$

④ Steel

Steel used under this project is equivalent to SD345/295.

⑤ Prestressed concrete steel

12S12.7B(SWPR7BL)(longitudinal prestressing) and 1S21.8(SWPR19L) (transverse prestressing) of prestressed concrete steel wire strands are used as PC concrete steel materials for this project.

v) The specification process for span length

The specification process for the bridge span length is shown in Fig. 2-2-20.

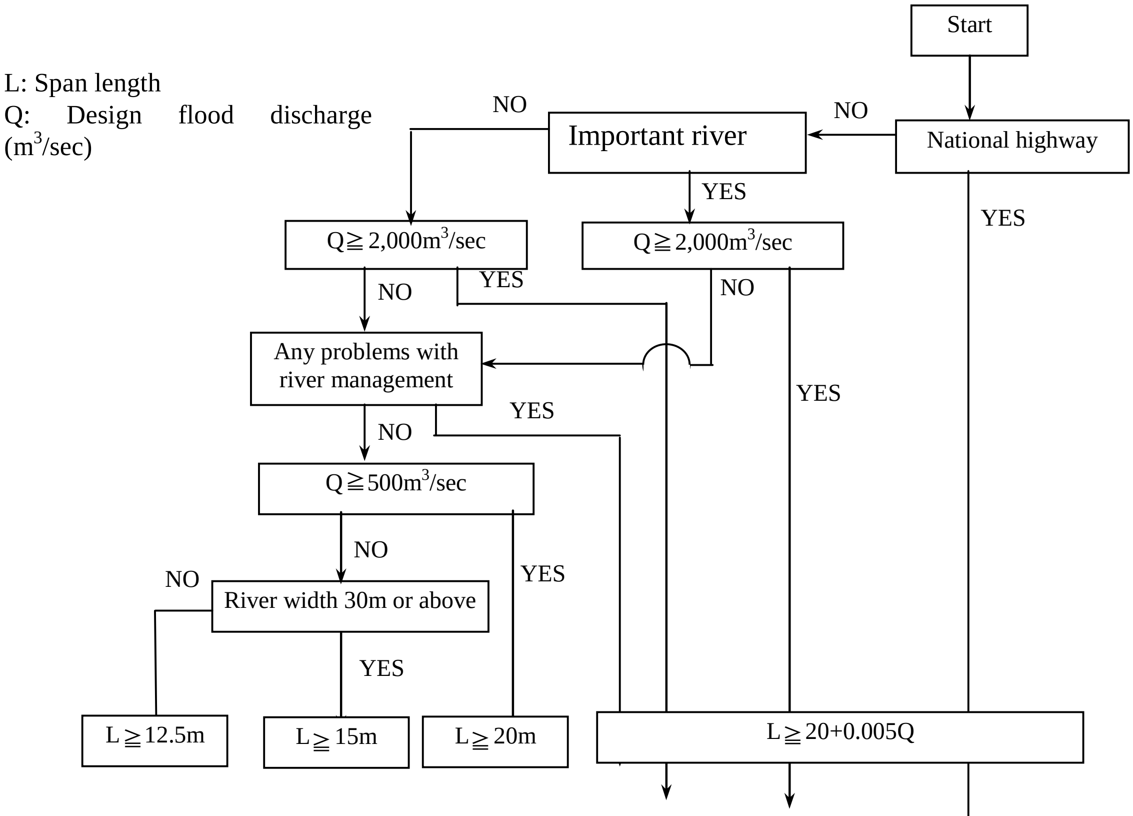


Fig. 2-2-20 Specification Process for the Bridge Span Length

Based on the specification process for span lenth, the span length of the project bridge was estimated to be L≧20＋0.005Q＝20+0.005×1200＝26m when the design flood discharge is Q=1200m m^3/sec.

(2) Width Plan

As stated in the policies concerning the bridge width in 2-1-4, the standard road cross section of the bridge is 9.7 meters in total (effective width,) consisting of roadway width of 3.35m×2=6.7m, bikeway width of 0.3m×2=0.6 m and walkway width of 1.2m×2=2.4m.

The standard road cross section of the earthwork is 11.7 meters in total (effective width,) consisting of roadway width of 3.35m×2=6.7m, bikeway width of 0.3m×2=0.6m, shoulder width of 1.2m×2=2.4m, and protection shoulder of 1.0m×2=2.0m.

(3) Studying the bridge length

Since the new bridge is built downstream of the existing Rukuru Bridge, the abutments need to be positioned not as close to the river side as the front faces of the existing abutment walls. Hence, the front faces of of the new bridge abutments should be positioned backward from the lines extended from the front faces of the existing abutment walls.

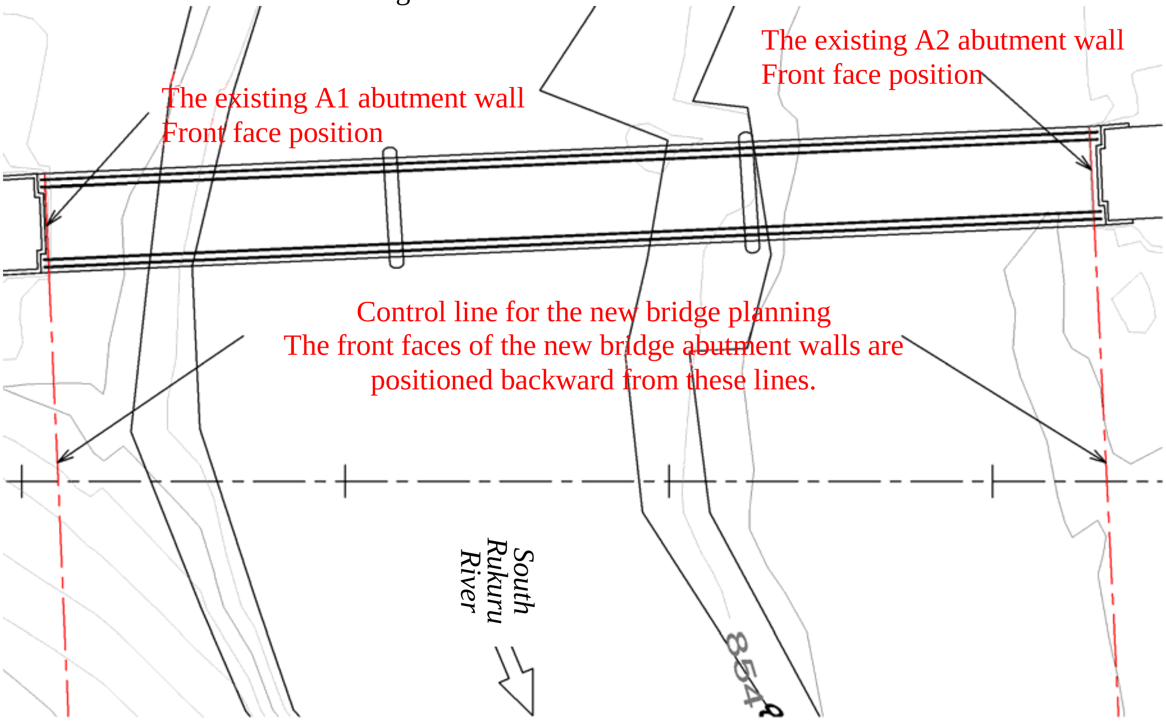


Fig. 2-2-21 Control Points for the New Bridge Planning

As a result, the A1 abutment was positioned at No.16+1.000 (the front face of the parapets) and the A2 abutment was positioned at No.19+8.500 (the front face of the parapets.) From this, the length of the new bridge must be 67.5 meters or above.

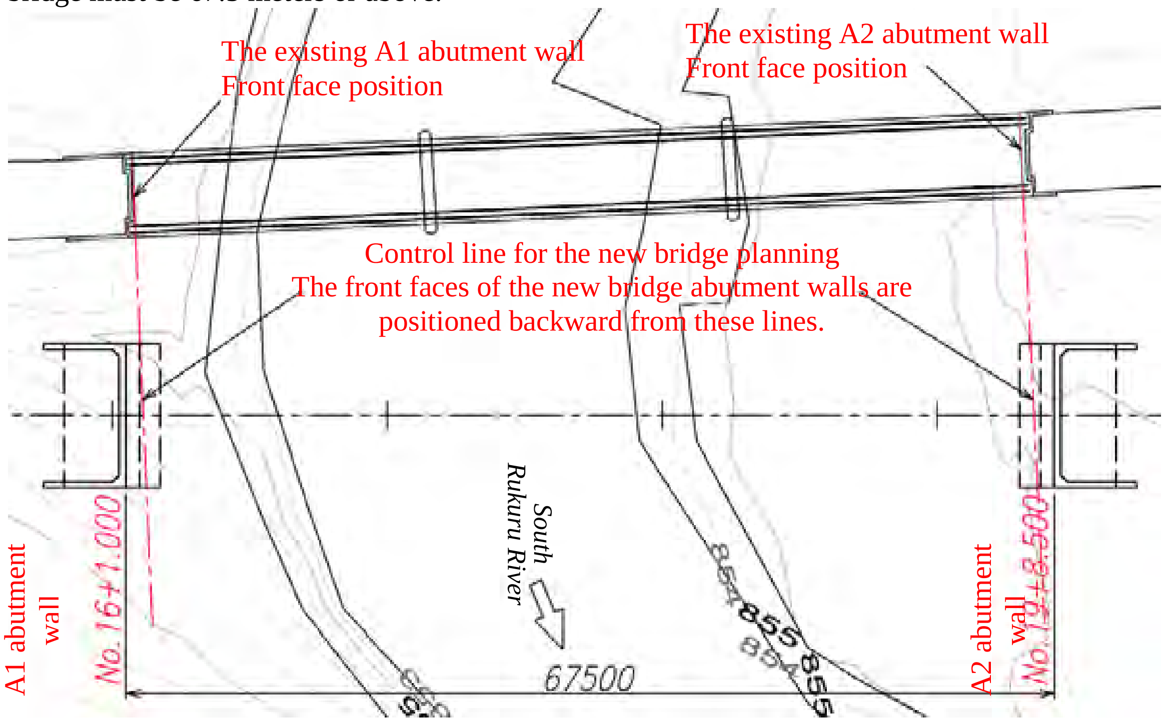


Fig. 2-2-22 The New Bridge Abutment Positions (minimum necessary bridge length)

If the A2 abutment is built in parallel with the control line (in parallel with bank protection,) the new bridge will make an oblique angle, and will make the bridge length slightly shorter. However, considering that construction of a skew bridge is less workable than that of a straight bridge and that the difference in length between the two bridge types is only 30 centimeters, a straight bridge was adopted for design.

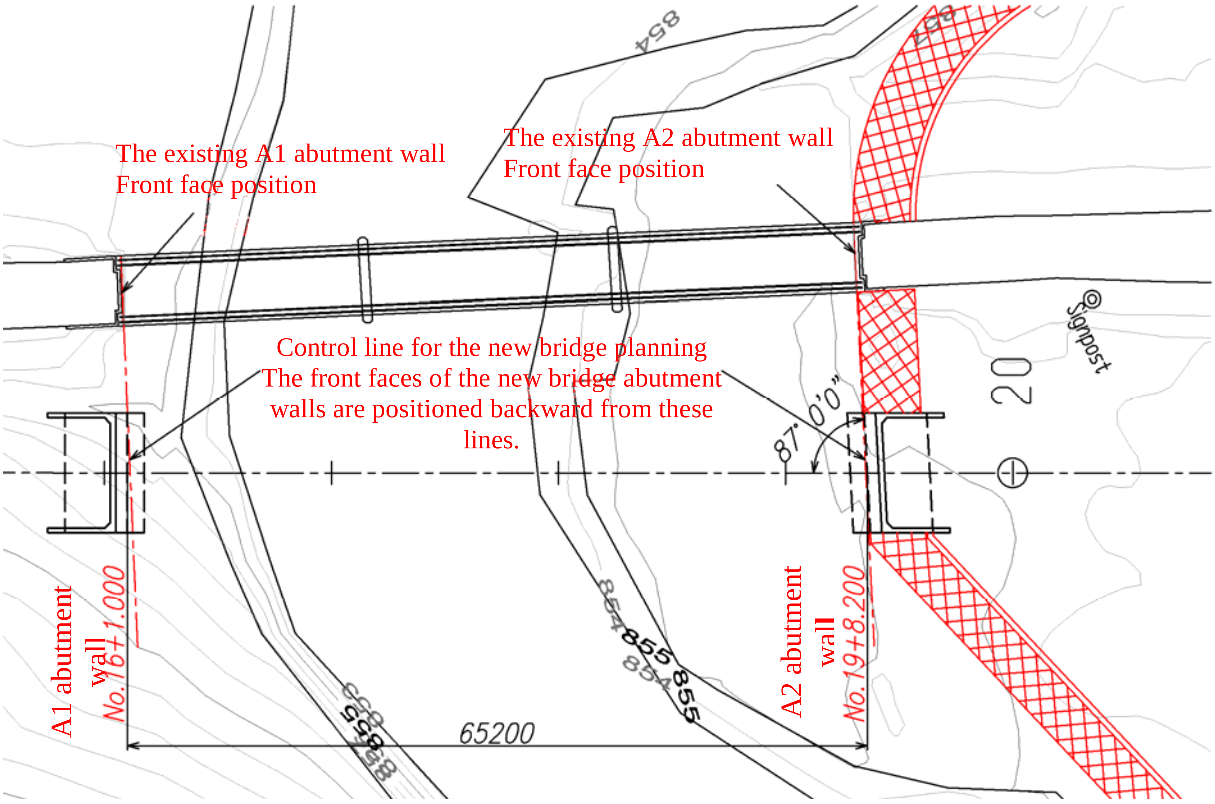


Fig. 2-2-23 Abutment Positions and Length

Since the hydrological analysis showed problems associated with the 67.5m-long bridge, the position of the A2 abutment was moved to the terminal point to secure the river cross section at the bridge location. As a result, the A2 abutment was positioned at No.19+15.000, and the bridge length was defined as 74.000 meters.

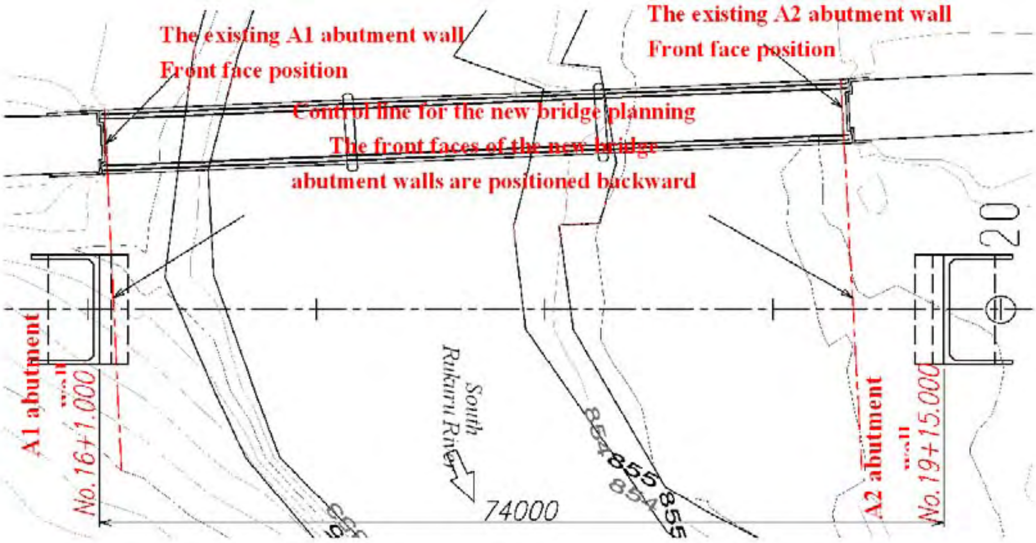


Fig. 2-2-24 New Bridge Abutment Positions

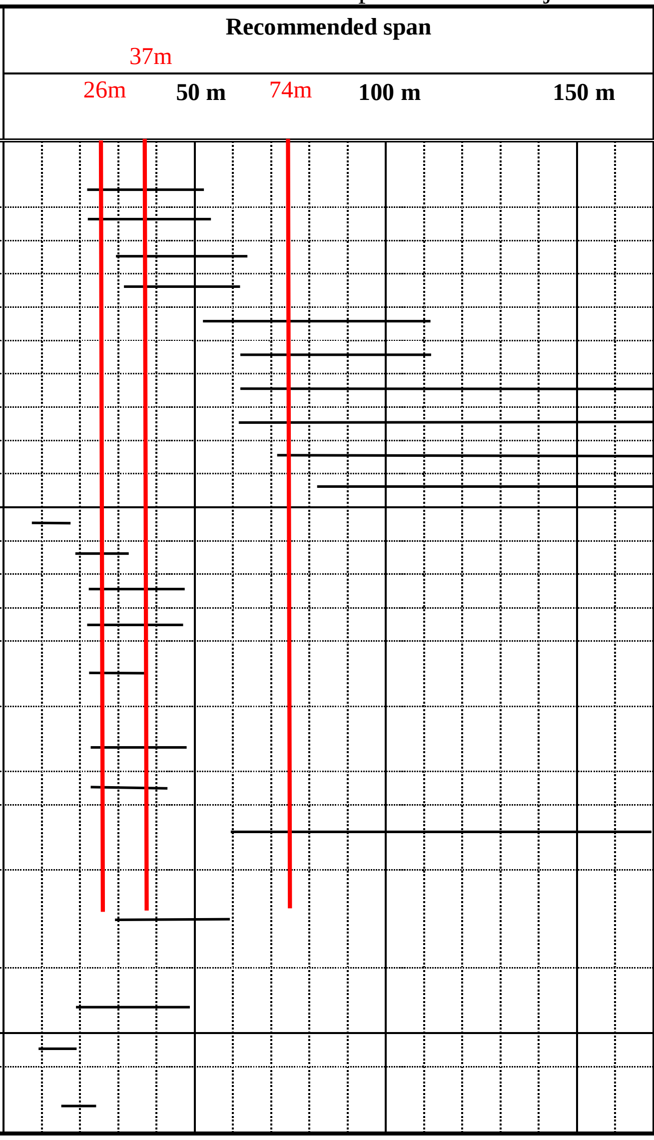
(4) Bridge type comparison

For different bridge options for comparison, the number of spans was calculated based on the standard span length determined from the design flood discharge, standard bridge types and their span length and past usage in Malawi to select an optimal bridge type with superior structural performance, construction efficiency, economic efficiency and maintenanciability.

Provided that the required bridge length is 74.0 meters and the standard span length is 26.0 meters, the following span allocation was used to identify a superstructure type from "Standard span" in Table 2-2-11

① Three-span bridge: 3@26.0m＝78.0m
② Two-span bridge: 2@37.0m＝74.0m
③ Simple bridge: 74.0m

Table 2-2-11 Standard Spans for the Project



Superstructure type		Curve applicable: Main structure	Curve applicable: Bridge deck	Girder height Span ratio
Steel bridge	Simple composite plate girder	○	○	1/18
Steel bridge	Simple plate girder	○	○	1/17
Steel bridge	Continuous plate girder	○	○	1/18
Steel bridge	Simple box girder	○	○	1/22
Steel bridge	Continuous box girder	○	○	1/23
Steel bridge	Simple truss	×	○	1/ 9
Steel bridge	Continuous truss	×	○	1/10
Steel bridge	Reverse Langer girder	×	○	1/6,5
Steel bridge	Reverse Lohse girder	×	○	1/6,5
Steel bridge	Arch	×	○	1/6,5
PC bridge	Pretentioned girder	×	○	1/15
PC bridge	Hollow slab	○	○	1/22
PC bridge	Simple T girder	×	○	1/17,5
PC bridge	Simple composite girder	×	○	1/15
PC bridge	Continuous T girder, composite girder	×	○	1/15
PC bridge	Continuous composite girder	×	○	1/16
PC bridge	Simple box girder	○	○	1/20
PC bridge	Continuous box girder (cantilever method)	○	○	1/18
PC bridge	Continuous box girder (Push-out or support method)	○	○	1/18
PC bridge	π shaped rigid frame ridge	×	○	1/32
RC Bridge	Hollow slab	○	○	1/20
RC Bridge	Continuous spandrel-filled **arch**	○	○	1/ 2

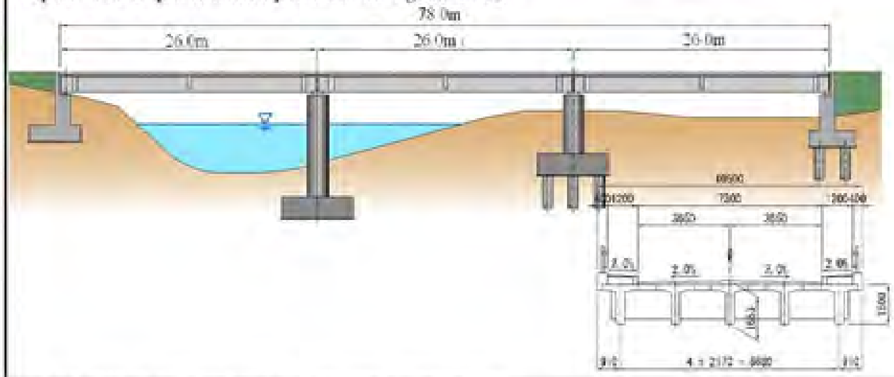
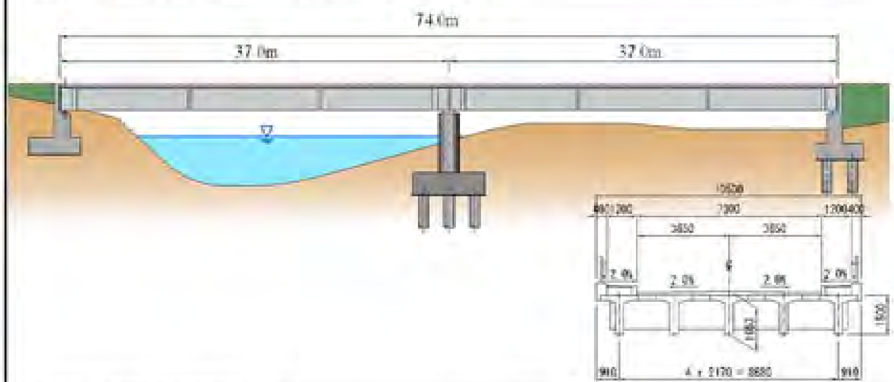
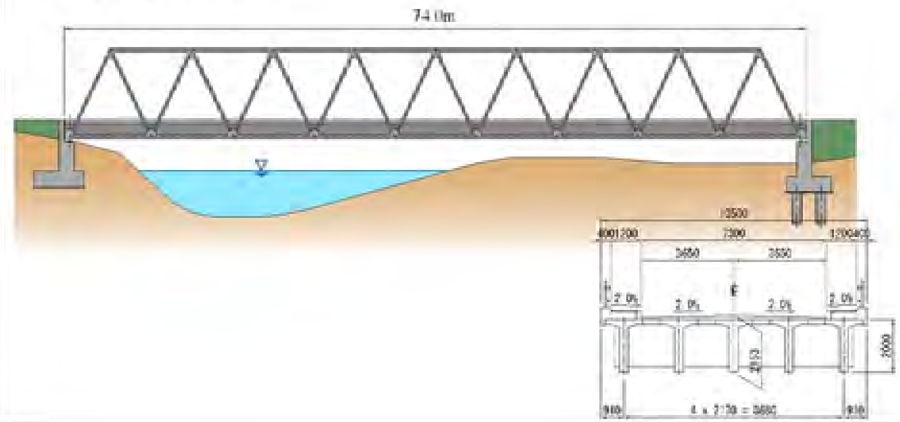
From the above table, the following three types were selected for comparison.

Table 2-2-12 Bridge Type Comparison

Option	Bridge type	Bridge structural type	# of spans	Span allocation
Option 1	PC bridge	PC three-span continuous T girder bridge	3	3@26.0=78.0m
Option 2	PC bridge	PC three-span continuous T girder bridge	2	2@37.0=74.0m
Option 3	Steel bridge	Steel simple truss bridge	1	74.0m

Table 2-2-13 shows a result of comparison among the above three options.

Table 2-2-13 Bridge type comparison table

Bridge Types	Characteristics		
Option 1: PC 3-span connected post-tensioned T girder bridge 	Structural features	• The structure is common for a PC girder type bridge. • The continuous structure connecting main girders on intermediate supports is superior in earthquake resistance. • Because the girder height is low, the profile height can be kept low (the same as in Option 3).	
	Work performance	• Because superstructure works are performed using erection girders, the progress of works is not affected by river water level fluctuations. • By securing a girder manufacturing yard, manufacturing of girders can be performed in parallel to substructure works. • Estimated work period: about 18 months.	
	Maintenance	• Because it is a concrete bridge, the bridge itself does not require maintenance. • Because the bridge has higher rigidity than a steel bridge, it is less likely to be damaged when hit by driftwood during a flood. • Because this option involves the largest number of piers in the river, it is disadvantaged in terms of scouring and other river management problems.	
	Performance in the river	• Due to the presence of 2 piers, the bridge is more prone to the impact of boulders and driftwood during floods. • The reduction of river cross-section caused by the placement of piers is the largest among the 3 options. • The impact of pier construction in the river on water environment is the largest among the 3 options.	
	Economy	• Because the superstructure involves longer bridge length albeit shorter span lengths, the total construction cost is similar to that in Option 2. • Relative estimated construction cost: 1.00	
	Overall evaluation	• The advantage in economy is similar to that in Option 2. • Due to the largest number of piers, this option is the most sensitive to the impact of boulders and driftwood during floods.	△
Option 2: PC 2-span connected post-tensioned T girder bridge 	Structural features	• The structure is common for a PC girder type bridge. • The continuous structure connecting main girders on the intermediate support is superior in earthquake resistance. • The girder height is higher than that in other options and the impact of road surface raising is larger. However, there is no restriction on the girder height.	
	Work performance	• Because superstructure works are performed using erection girders, the progress of works is not affected by river water level fluctuations. • By securing a girder manufacturing yard, manufacturing of girders can be performed in parallel to substructure works. • Estimated work period: about 17 months.	
	Maintenance	• Because it is a concrete bridge, the bridge itself does not require maintenance. • Because the bridge has higher rigidity than a steel bridge, it is less likely to be damaged when hit by driftwood during a flood. • Although a pier is placed in the river, maintenance problems are less severe than in Option 1, because only 1 pier is needed.	
	Performance in the river	• Although the impact of boulders and driftwood during floods is considerable, the impact is relatively small because there is only 1 pier. • The reduction of river cross-section caused by the placement of the pier is smaller than that in Option 1. • The impact of pier construction in the river on water environment is smaller than that in Option 1.	
	Economy	• Because the superstructure involves shorter bridge length albeit longer span lengths, the total construction cost is similar to that in Option 1. • Relative estimated construction cost: 1.00	
	Overall evaluation	• Because there is only 1 pier, the impact of boulders and driftwood is smaller than that in Option 1. • Although the girder height is higher than that in other options, this causes no problem because there is no restriction on the girder height.	◎
Option 3: Steel simple truss bridge 	Structural features	• This option uses a steel truss structure that is common in long-span bridges. • This structure is superior in earthquake protection because of the lighter weight of superstructure as compared with a concrete bridge. • Although the through bridge type is advantageous in securing a clear headway under girder, the amount of road surface raising is the same as in Option 1.	
	Work performance	• Superstructure works require temporary bents in the river and therefore are affected by water rise in the rainy season. • All structural members (steel materials) must be procured/produced in Japan or a third country. • Estimated work period: about 15 months.	
	Maintenance	• Because it is a steel bridge, regular recoating is needed. • Restoration is difficult in the event of natural disasters, traffic accidents, etc. causing damage to major parts. • Due to the lack of piers, this option is the most advantageous in river maintenance among the 3 options.	
	Performance in the river	• Due to the lack of piers, the bridge is completely free from the impact of boulders and driftwood during floods. • Because river cross-section is not reduced by the placement of piers, this option provides the highest safety against floods. • Although piers are not placed, the impact of temporary bent works on water environment is similar to the impact in other options.	
	Economy	• Although this is the most economical option in terms of substructure works, it is the least economical among the 3 options in terms of the total construction cost including superstructure works. • Relative estimated construction cost: 1.38	
	Overall evaluation	• Due to the lack of piers, the bridge is completely free from the impact of boulders and driftwood during floods. • This option is disadvantageous in terms of economy because maintenance cost is needed in addition to initial cost.	○

(5) Studying substructure work/ foundation work methods

1) Selection of a support layer

From the geological survey, highly stiff rock beds were found 4-5 meters below the surface of the ground, and these beds shall be used as a support later for the bridge. Fig. 2-2-24 shows the estimated position of the support layer.

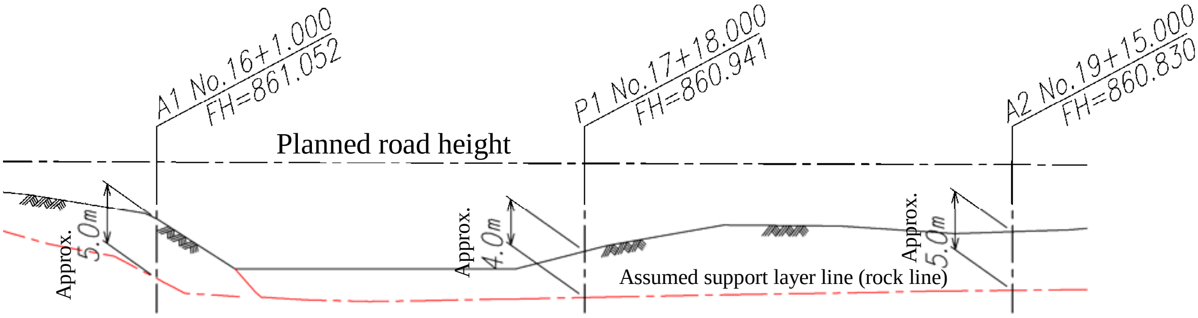


Fig. 2-2-25 Assumed Position/ Line of the Support Layer

2) Substructure work/ foundation work methods

Table 2-2-14 is a method selection table for the substructure works, and

Table 2-2-15 is a selection table for the foundation works.
From the planned height and burial into the support ground (50cm burial into the support layer,) the height of the abutments was set as 12 meters. Hence, from the table below, Reverse T-style abutment was adopted for the bridge, and elliptical piers was adopted for bridge piers in consideration for their installation in the river.

Table 2-2-14 A method selection table for the substructure works

Bridge part	Structure type	Applicable height (m) 10 20 30	Characteristics
Abutment	1. Gravity type		With shallow support ground, the gravity type is suitable for direct foundation.
	2. Reverse T-style		Used in many bridges. Suitable for direct foundation/ pile foundation.
	3. Buttressed type		Suitable for tall abutments. Few materials are used for this type, but the lead time is long.
	4. Box type		Designed for tall abutments. The lead time is slightly long.
Pier	1. Column type		Low piers. Suitable for stringent intersection conditions and installation in a river.
	2. Rigid frame type		Relatively tall piers. Suitable for wide bridges. Their installation in a river may hinder water flow in time of flooding.
	3. Pile bent type		While they are the most cost efficient piers, they are not suitable for bridges with high horizontal force. Their installation in a river may hinder water flow in time of flooding.
	4. Elliptical type		Tall bridge piers. Suitable for bridges with high external force.

Provided that the support layer for the bridge foundation is in a relatively shallow area, that rocks are used as the support ground and that sediments on the river beds in the area above the support ground are cobblestones (megaliths,) direct foundation was selected for the bridge from the table below.

Table 2-2-15 Construction Method Selection Table for the Foundation

Selection requirements			Foundation types	Direct foundation	Cast pile foundation			Inner excavation pile foundation						Cast in-situ pile foundaiton				Caisson foundation		Steel pipe sheet pile foundation	underground continuous wall foundation
								PHC pile			Steel pipe pile										
					RC pile	PHC pile	Steel pipe pile	Final impact driving method	Blast agitation	Concrete impact	Final impact driving method	Blast agitation	Concrete impact	All casing	Reverse	Earth drill	Chicago board	Pneumatic	Open		
Ground requirements	Below support layer	Soft ground in the interlayer		△	○	○	○	○	○	○	○	○	○	○	○	○	×	○	○	○	○
		An extremely hard layer inside the inter layer		○	×	△	△	○	○	○	○	○	○	△	○	△	○	○	△	△	○
		Gravel in the interlayer	Gravel size 5 cm or below	○	△	△	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			Gravel size 5 cm〜10 cm	○	×	△	△	△	△	△	△	△	△	○	○	△	○	○	○	△	○
			Gravel size 10 cm〜50 cm	○	×	×	×	×	×	×	×	×	×	△	×	×	○	○	△	×	△
		The layer has liquefiable ground		△	△	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Support later Conditions of the support layer The surface of	Support layer depth	Below 5 m	○	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
			5〜15 m	△	○	○	○	○	○	○	○	○	○	○	△	○	○	○	○	△	△
			15〜25 m	×	△	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
			25〜40 m	×	×	○	○	○	○	○	○	○	○	○	○	△	△	○	○	○	○
			40〜60 m	×	×	△	○	△	△	△	○	○	○	△	○	×	×	△	○	○	○
			60 m or above	×	×	×	△	×	×	×	×	×	×	×	△	×	×	×	△	△	△
		Soil properties of the support layer	Cohesivvve soil (20≦N)	○	○	○	○	○	×	△	○	×	△	○	○	○	○	○	○	○	○
			Sand/ gravel (30≦ N)	○	○	○	○	○	○	×	○	○	×	○	○	○	○	○	○	○	○
		High gradient (30º or above)		○	×	△	○	△	△	△	○	○	○	○	△	△	○	○	△	△	△
		The surface of the support layer is severely uneven		○	△	△	○	△	△	△	○	△	△	○	○	○	○	○	△	△	○
	Groundwater	Groundwater level is close to the ground surface		△	○	○	○	○	○	○	○	○	○	○	○	△	△	○	○	○	○
		Significant amount of spring water		△	○	○	○	○	○	○	○	○	○	○	○	△	×	○	○	○	△
		Artesian groundwater 2 m above the ground surface		×	○	○	○	×	×	×	×	×	×	×	×	×	×	△	△	○	×
		Groundwater velocity is 3m/ min or above		×	○	○	○	○	×	×	○	×	×	×	×	×	×	○	△	○	×
Structural properties	Load size	Low vertical load (span length 20m or below)		○	○	○	○	○	○	○	○	○	○	○	○	○	○	×	△	×	×
		Moderate vertical load (span length 20m to 50m)		○	△	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
		High vertical load (span length 50m)		○	×	△	○	△	△	△	○	○	○	○	○	△	○	○	○	○	○
		Horizontal load is lower than vertical load		○	○	○	○	○	○	○	○	○	○	○	○	○	○	△	△	△	△
		Horizontal load is higher than vertical load		○	×	△	○	△	△	△	○	○	○	○	○	○	○	○	○	○	○
	Support type		Support pile		○	○	○	○	○	○	○	○	○	○	○	○	○				
			Friction pile		○	○								○	○	○					
Construction requirements	Construction on water		Water depth below 5m	○	○	○	○	△	△	△	△	△	△	×	○	△	×	△	△	○	×
			Water depth 5m or above	×	△	△	○	△	△	△	△	△	△	×	△	×	×	△	△	○	×
	Limited work space			○	△	△	△	△	△	△	△	△	△	△	△	△	○	△	△	×	△
	Batter pile construction				△	○	○	×	×	×	△	△	△	△	×	×	×				
	Effects of toxic gas			△	○	○	○	○	○	○	○	○	○	○	○	○	×	×	○	○	○
	Surrounding environment		Oscillation noise measures	○	×	×	×	△	○	○	△	○	○	△	○	○	○	○	○	△	○
			Effects on adjacent structures	○	×	×	△	△	○	○	△	○	○	○	○	○	△	△	△	△	○

Fig. 2-2-26 shows the geometry and height of the substructure works. Table 2-2-16 is a calculation table for the structural height.

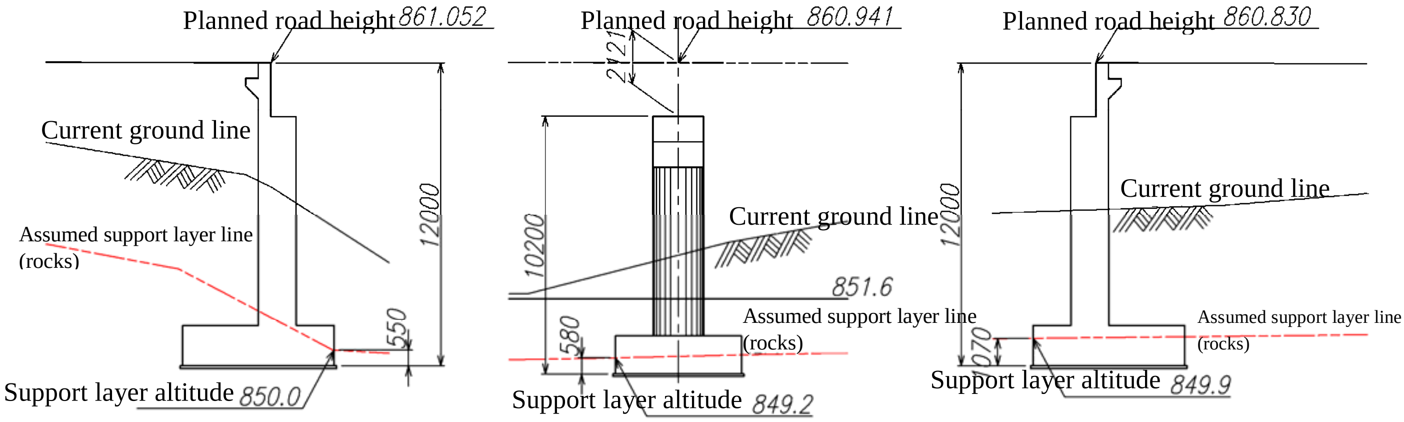


Fig. 2-2-26 Substructure Work Geometry and Structural Height

Table 2-2-16 Calculation of Structural Height of the Substructure Works

	A1 Abutment	P1 Pier	A2 Abutment
Planned road height	861.052	860.941	860.830
Support layer ground height	849.600	849.200	849.900
Burial into the support ground (rough indication)	0.500	0.500	0.500
Lower end altitude of the substructure works (rough indication)	849.100	849.200	849.400
Structural height of the upper works	-	2.121	-
Minimum substructure work structural height	11.952	10.120	11.430
Decision height of the substructure works	12.000	10.200	12.000
Lower end altitude of the lower part	849.052	848.620	848.830
Burial into the support ground	0.548	0.580	1.070

(6) Studying the bridge crossfall

In the design criteria of Malawi, the standard crossfall of carriageway is 2.5%. And, the crossfalls of the carriageways of the Main Road No. 5 bridges (the Lwazi Bridge and the Nankokwe Bridge) and the Bakili Muluzi Bridge are all 2.5%. Hence, for the South Rukuru Bridge, the crossfall of its carriageway was defined as 2.5%.

On the other hand, the crossfalls of the footways in the Lwazi Bridge and the Bakili Muluzi Bridge are 3%, which indicates that they are highly steep slopes. In consideration of walking conditions, a crossfall of a footway is ideally 0%, but this also needs to take into account a drainage gradient, which must be set as a minimum of 0.3%. Hence, even a 1% crossfall is considered sufficient for a footway.

Fig. 2-2-28 shows the crossfall of the South Rukuru Bridge.

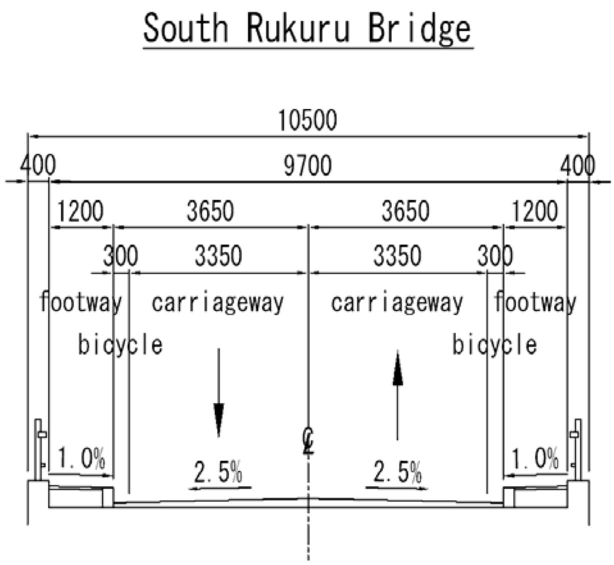


Fig. 2-2-27 Crossfall of the South Rukuru Bridge

(7) Studying bank/ bed protection works

Since the current South Rukuru River and the Lura River are both natural rivers, their channels are kept without installation of revetments, and there are no bank/ bed protection works in the periphery of the current bridge abutments and piers or downstream/ upstream of the river banks. Since they are natural rivers, a large amount of sediments such as soil and stones transferred from the upstream and the branch river remain at the upstream and downstream of the current bridge, making the flow capacity insufficient and preventing smooth flow of flood water. To secure safe and smooth flow of flood water after completion of the bridge construction, bank/ bed protection works for the upstream and downstream of the bridge location shall be studied in consideration of the junction between the South Rukuru River and the Lura River, where the bridge is built.

1) The current river conditions

i) The South Rukuru River

There are steep cliffs at the bridge location at the right bank of the South Rukuru River, and rocks are exposed near the river bed. Since the center of the flow is close to the right bank, the water depth is high on this side. On the other hand, since the left bank is the opposite side of water flow, and is the point where the river meets with the Lura River, mud and sand gravel transferred during flooding are accumulated on this side, making the water depth low. It was confirmed from a geological survey that while the river bed is composed of gravel and sand of large particle size, the gravel layer is not as thick as it was predicted, and that the foundation is composed of rocks.

Since the foundation ground (rock beds) for the A1 abutment, the P1 piers and the A2 abutment is shallower than the scour depth of 3.0 meters, no particular scour-related problems are estimated.

Still, provided that the bridge access roads reinforced with embankment will be built on the current ground in the periphery of the back of the A1 Abutment and the A2 Abutment, a measure will be needed to secure bank ground within the area of the foundation ground. The measure is to install revetments on the bank ground at the upstream and downstream of the abutments to secure a channel cross section for smooth water flow in time of flooding, and this requires discharge of sediments in the river after the completion.

Given that the South Rukuru River is a high-gradient river due to its location in a mountainous area and that the fast flow of water, which contains sand and cobblestones transferred from the upstream and the Lura River, will affect the revetments, scour measures and a resilient structure will be required to protect the front face of the revetments. To this end, bank protection works and bed protection works should be implemented in front of the revetments to protect the banks from floods.

ii) The Lura River

The basin and channel of the Lura River are natural, and currently there are no river structures such as revetments and other protection works within the river. With the deposition of megaliths, cobblestones and sand on the river bed within 200 meters from the junction, where the channel surrounded by mountains becomes a flat land, the flow cross section has been reduced.

Since the current flow capacity of the channel cross section within this range is insufficient for flow of flood water in the Lura River basin, the sediments in the river needs to be excavated and cleared to improve the flow capacity. To this end, excavation of the sediments in the river needs to be conducted, and also bank protection works need to be installed for protection of the river banks after the excavation.

While the left bank of this range is tall because of a dike piled up after excavation of megaliths and cobblestones transferred with floods, the edge of the upstream side resting on the existing ground is kept low, preventing the dike from functioning as bank protection within this range. Even in the case when a flood occurs only at the Lura River and not at the South Rukuru River, overflow may occur at the edge of the dike. When overflow occurs, it is blocked by the embankment of the access road on the side of A2, and results in waterlogging, which has a risk of affecting the embankment. This can be prevented with utilization of a drainage ditch at the sag section of the access road embankment as well as channel improvement with installation of revetments. Use of the both methods will be studied and the scale of the work is to be decided.

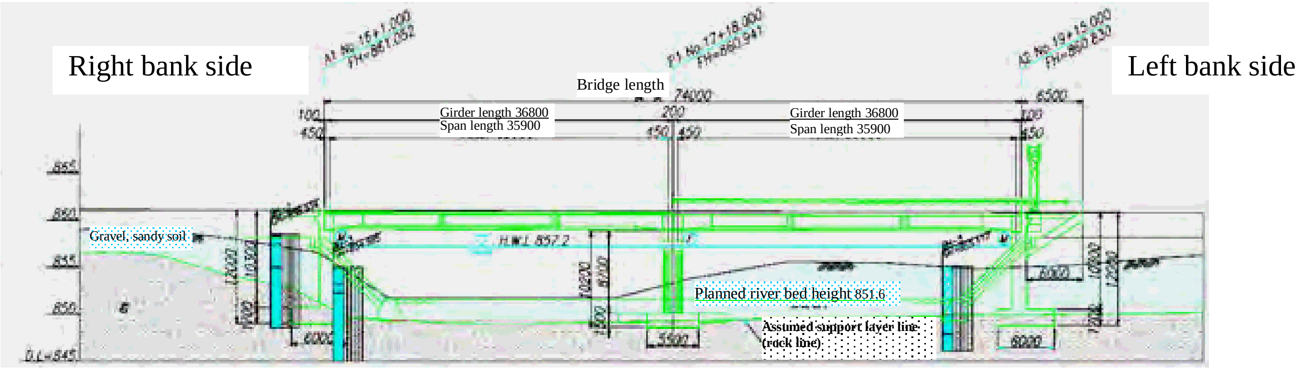


Fig. 2-2-28 Cross Section Diagram of the Bridge Location

2) Studying the scope and the structural type of bank protection works

Bank protection methods include direct methods that use ripraps, wire mats and cobblestones and indirect methods such as spurs, training levees and vane-type structures. Since indirect methods are costly, a direct method was adopted for the project.

Direct methods include ripraps, wire mats and cobblestones, which have the following characteristics;

① Ripraps are widely used for slope protection and foot protection. The method is relatively inexpensive with simple implementation, and can be easily maintained and managed as it can be used as a countermeasure for minor scour. However, ripraps are easily removed by water, and affect the surrounding vegetation until they become stable.

② Wire mats are relatively inexpensive, and can be easily maintained and managed. However, stones filling the mat have a risk of being scattered with scour. Also, durability of the mat needs to be taken into consideration.

③ Cobblestone masonry is widely used as it is hardly moved with water flow and is highly adaptable to flow velocity. The weakness is that the method is less workable.

With regard to the riprap method, it was concluded from a brief study on stable weight at the bridge location that ripraps of 0.5m to 0.8m median particle diameter are needed, but obtaining the necessary amount of such stones is considered difficult. With the method using wire mats, flow of cobblestones of 20cm particle diameter may damage the mat materials during collisions, which create problems such as scattering of infilling materials etc. Because its capacity to deal with flow velocity in the proximity of bank protection in time of flooding is as high as 4-8m/s, cobblestone masonry, which has been implemented in Malawi, will be used as a bank protection measure despite its relatively low workability.

As a scope of bank protection around the left bank abutment, it will be implemented up to the slope and the crown that protect the front face of the abutment as bank protection for the foundation ground of the access road embankment. Crown works will be implemented in consideration of erosion of rainwater at the crown.

Height of revetments at the front face of the bridge abutments is defined as 857.2m+1.0m. For embankment of the access roads at the Lura River side of the A2 Abutment, slope pavement will be implemented in the area affected by overflow and rainwater from the Lura River in time of flooding.

As a scope of bank protection in the periphery of the abutments, protection works will be installed in the area of sediment discharge after the completion, and the edge of the revetments will be reinforced by wire mats, which will be attached to the existing ground. For reasons of availability of the materials, size of wire mats is defined as 1.9m (H)*1.0m (W)*2.0(L).

Because rocks are exposed on the right bank, no special protection works will be needed on this side. However, since embankment for the access road, which stretches to the right bank abutment, will be implemented on the existing ground, mortared masonry will be built in the area needed for securing the foundation ground of embankment.

Mortared masonry will be also built at the required area upstream of the right bank abutment for securing the foundation ground of the embankment. This is expected to secure smooth water flow in time of flooding, potentially lowering the water level at the bridge location.

(8) Studying access road

1) Studying pavement configuration

i) Design period

The design period for the pavement of the relevant road is set to be 15 years according to Table 2-2-17.

Table 2-2-17 Pavement Design Period

Design data reliability	Importance/level of service	
	Low	High
Low	10 - 15 years	15 years
High	10 - 20 years	15 - 20 years

* Code of Practice for the Design of Road Pavements (SATCC) Table2.1

Design data reliability: Low ⇒ due to uncertainty of future traffic volume
Importance/level of service: High due to the status as an international trunk road

ii) Design traffic volume

a) Calculation of AADT (Annual Average Daily Traffic)

The assumption based on the average traffic volume during the traffic volume survey (7 days) in this study gives the following.

(195+222+254+218+236+277+225) / 7 = 232 (vehicles/12h, bidirectional)

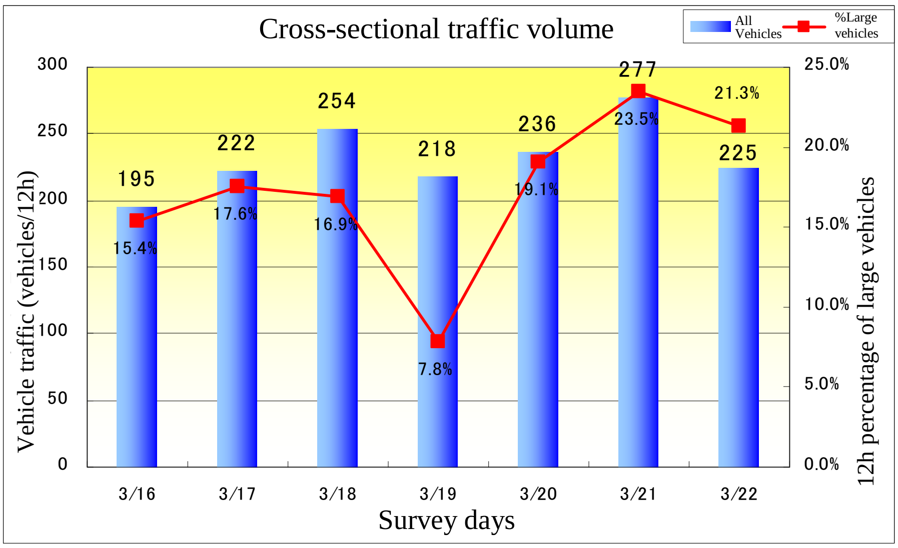


Fig. 2-2-29 Traffic Volume during Survey Period (12h Traffic of Automobiles)

For the conversion to daily traffic volume, we use the weekday day-night ratio of 1.46 as shown in Table 2-2-18.

Table 2-2-18 Survey Result on the Daytime and Nighttime 12h Traffic of Automobiles

March 19 (Thursday)	Automobile traffic (vehicles/12h)
Daytime 12h traffic (6:00-18:00)	218
Nighttime 12h traffic (18:00-6:00)	101

Day-night ratio = 24h traffic / daytime 12h traffic = (218 + 101) / 218 = 1.46
(From the 24h traffic volume observed on March 19)

AADT=232×1.46＝338.7 (vehicles/day, bidirectional)

b) Calculation of AADT by vehicle category

The assumption as shown in Table 2-2-19is used according to the percentage of each vehicle category in the traffic volume during the entire survey period (total of 12h traffic volume on 7 survey days).

Table 2-2-19 Composition of Traffic by Vehicle Category

Vehicle category	All vehicle traffic (vehicles/12h, 7 days)	Traffic by vehicle category (vehicles/12h, 7 days)	Composition (%)
Passenger car	1,627	471	28.9
Bus and Microbus		382	23.5
Light truck (2 axles)		487	29.9
Heavy truck (3 axles and more)		287	17.6

From the above, the traffic volume (AADT) for each vehicle category is calculated as follows.

Passenger car: 338.7 × 28.9% ＝ 97.9 (vehicles/day, bidirectional)
Bus and microbus: 338.7 × 23.5% ＝ 79.6 (vehicles/day, bidirectional)
Light truck: 338.7 × 29.9% ＝ 101.3 (vehicles/day, bidirectional)
Heavy truck: 338.7 × 17.6% ＝ 59.6 (vehicles/day, bidirectional)

c) Calculation of unidirectional traffic volume

Unidirectional traffic volume is used as the traffic volume in pavement design.
For the conversion to unidirectional traffic volume, the mean value for the percentage of traffic in heavier direction throughout the survey period is assumed to be 52.3% as shown in Table 2-2-20.

Table 2-2-20 Percentage of Traffic in Heavier Direction during Survey Period

Survey day		Cross-sectional traffic volume (vehicles/12h)	Unidirectional traffic volume (vehicles/12h)	Percentage of traffic in heavier direction
3/16	Mo.	195	102	52.3
3/17	Tu.	222	118	53.2
3/18	We.	254	131	51.6
3/19	Th.	218	118	54.1
3/20	Fr.	236	121	51.3
3/21	Sa.	277	145	52.4
3/22	Su.	225	115	51.1
Mean				52.3

From the above, the unidirectional traffic volume for each vehicle category is calculated as follows.

Passenger car: 97.9 × 52.3% ＝ 51.2 (vehicles/day, unidirectional)
Bus and microbus: 79.6 × 52.3% ＝ 41.6 (vehicles/day, unidirectional)
Light truck: 101.3 × 52.3% ＝ 53.0 (vehicles/day, unidirectional)
Heavy truck: 59.6 × 52.3% ＝ 31.2 (vehicles/day, unidirectional)

iii) Total traffic volume by vehicle category during design period

SATCC uses the annual growth rate of traffic volume generally in the range from 2 to 15%.

* Code of Practice for the Design of Road Pavements(SATCC) p2-2

In the case of this route, we use the growth rate of 8% per year, considering the effects of the renovation of South Rukuru Bridge in improving the reliability as an arterial route for international physical distribution and the expected increase in the demand for cargo transport to the uranium mine.

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

T: Design traffic volume (1: passenger car, 2: bus and microbus, 3: light truck, 4: heavy truck)

r: Growth rate (8%)

p: Design period (15 years)

* Code of Practice for the Design of Road Pavements(SATCC) p2-2

From the above, the total traffic volume by vehicle category during the design period is calculated as follows.

$$DT_1 = 51.2 \times 365 \times \{(1+8/100)^{15} - 1\} / (8/100) = 507{,}418.6 \text{ (vehicles/15 years)}$$
$$DT_2 = 41.6 \times 365 \times \{(1+8//100)^{15} - 1\} / (8//100) = 412{,}277.6 \text{(vehicles/15 years)}$$
$$DT_3 = 53.0 \times 365 \times \{(1+8//100)^{15} - 1\} / (8//100) = 525{,}257.6 \text{(vehicles/15 years)}$$
$$DT_4 = 31.2 \times 365 \times \{(1+8//100)^{15} - 1\} / (8//100) = 309{,}208/2 \text{(vehicles/15 years)}$$

iv) Pavement destruction factor

The pavement destruction factor is set at n=4 as shown in Table 2-2-21, assuming that both pavement base and subbase are granular.

Table 2-2-21 Pavement Destruction Factor

Pavement base/subbase	Recommended n
Granular/granular	4
Granular/cemented	3
Cemented/cemented	4.5
Bituminous/granular	4
Bituminous/cemented	4

* Code of Practice for the Design of Road Pavements (SATCC) p2-2

v) Equivalent axle load factor

The equivalent axle load factor is calculated for each vehicle category (axle load range) from Table 2-2-22.

Table 2-2-22 Equivalent Axle Load Factor

Axle loads measured in kg				Axle loads measured in kN			
Axle load range (kg)	n = 3	n = 4	n = 4.5	Axle load range (kN)	n = 3	n = 4	n = 4.5
Less than 1500	-	-	-	Less than 15	-	-	-
1500 - 2499	.02	-	-	15 - 24	.02	-	-
2500 - 3499	.05	.02	.01	25 - 34	.05	.02	.01
3500 - 4499	.12	.06	.05	35 - 44	.13	.06	.05
4500 - 5499	.24	.15	.12	45 - 54	.24	.15	.12
5500 - 6499	.41	.30	.26	55 - 64	.42	.32	.28
6500 - 7499	.64	.56	.52	65 - 74	.66	.58	.55
7500 - 8499	.95	.95	.94	75 - 84	.99	.99	1.00
8500 - 9499	1.35	1.51	1.59	85 - 94	1.41	1.59	1.69
9500 - 10499	1.85	2.29	2.55	95 - 104	1.94	2.42	2.71
10500 - 11499	2.46	3.34	3.90	105 - 114	2.58	3.55	4.16
11500 - 12499	3.20	4.72	5.75	115 - 124	3.35	5.02	6.15
12500 - 13499	4.06	6.50	8.22	125 - 134	4.26	6.92	8.82
13500 - 14499	5.07	8.73	11.46	135 - 144	5.32	9.3	12.31
14500 - 15499	6.23	11.49	15.61	145 - 154	6.54	12.26	16.79
15500 - 16499	7.56	14.87	20.85	155 - 164	7.94	15.88	22.45
16500 - 17499	9.06	18.93	27.37	165 - 174	9.53	20.24	29.50
17500 - 18499	10.76	23.78	35.37	175 - 184	11.32	25.44	38.15
18500 - 19499	12.65	29.51	45.09	185 - 194	13.31	31.59	48.67
19500 - 20499	14.75	36.22	56.77	195 - 204	15.53	38.79	61.32

* Code of Practice for the Design of Road Pavements(SATCC) Table2.3

Table 2-2-23 Equivalent Axle Load Factor by Vehicle Category

Vehicle category	Axle load	Equivalent axle load factor
Passenger car	8 kN	—
Bus and microbus	50 kN	0.15
Light truck	50 kN	0.15
Heavy truck	100 kN	2.42

The value for heavy trucks is set following the example of maximum axle load in vehicle regulation, and those for buses and light trucks are set at 50% of the axle load of heavy trucks.

vi) Level of service

The level of service according to the road type is set to be 90% as shown in Table 2-2-24.

Table 2-2-24 Level of Service According to Road Type

Road type	Design traffic loading	Comment
Single carriageway		
Paved road width 4.5 m or less	Up to twice the sum of the ESAs in each direction*	At least the total traffic must be designed for as there will be significant overlap in each direction. For widths of 3.5m or less, double the total should be used due to channelisation
Paved road width 4.5 m to 6.0 m	80% of the sum of the ESAs in each direction	To allow for considerable overlap in the central section of the road
Paved road width more than 6.0 m	Total ESAs in the most heavily trafficked direction	No overlap effectively, vehicles remaining in lanes
Dual carriageway		
Less than 2,000 commercial vehicles per day in one direction	90% of the total ESAs in the direction	The majority of heavy vehicles will travel in one lane effectively
More than 2,000 commercial vehicles per day in one direction	80% of the total ESAs in the direction	The majority of heavy vehicles will still travel in one lane effectively, but greater congestion leads to more lane switching
* Judicious to use double the total ESAs expected, as normally these are low trafficked roads and this may give little difference in pavement structure.		

* Code of Practice for the Design of Road Pavements(SATCC) Table2.4

vii) Calculation of design ESAs

From the above consideration, the design axle load for the determination of pavement configuration is calculated as shown in Table 2-2-25.

Table 2-2-25 Equivalent Axle Load Factor by Vehicle Category

Vehicle category	DT	Equivalent axle load factor	Level of service	ESAs
Passenger car	507,418.6	—	0.9	0.0
Bus and microbus	412,277.6	0.15	0.9	55,657.5
Light truck	525,257.6	0.15	0.9	70,909.8
Heavy truck	309,208.2	2.42	0.9	673,455.5
Total				800,022.8

viii) Determination of traffic class designation

The ESAs (1.4 million) in the above and Table 2-2-26 indicate the traffic class designation of T3.

Table 2-2-26 Traffic Class Designation

Traffic class designation								
Traffic ranges (million ESAs)	T1	T2	T3	T4	T5	T6	T7	T8
	< 0.3	0.3 - 0.7	0.7 - 1.5	1.5 - 3	3 - 6	6 - 10	10 - 17	17 - 30

* Code of Practice for the Design of Road Pavements(SATCC) Table2.5

ix) Subgrade design

Regarding the design CBR of the subgrade, we assume the CBR of 12% considering the facts that the subgrade is expected to have exposed rock in cut sections and that the works in embankment sections can utilize part of the high-quality soft rock material from the excavated earth. In this case, the subgrade class designation will be S4 according to Table 2-2-27.

Table 2-2-27 Subgrade Class Designation

Subgrade class designation						
Subgrade CBR ranges (%)	S1	S2	S3	S4	S5	S6
	2	3 - 4	5 - 7	8 - 14	15 - 29	30+

Code of Practice for the Design of Road Pavements(SATCC) Table3.1

x) Determination of pavement configuration

Because of the relatively heavy rain in the rainy season, the vicinities of South Rukuru Bridge are considered to fall under the regional classification of Wet Regions, and the materials for the road base and the subbase are assumed to be granular as mentioned above. The roadbed class designation is W1.

The standard pavement configuration will be as shown in Fig. 2-2-30 according to the Chart on the next page.

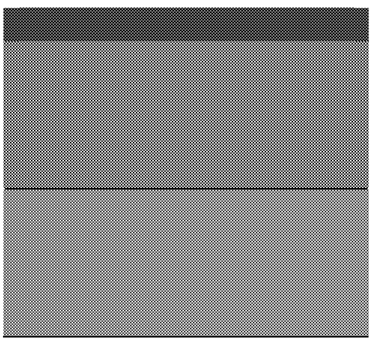


Fig. 2-2-30 Standard Pavement Configuration of South Rukuru Bridge

Table 2-2-28 Standard Pavement Configuration

CHART W1 : Granular base / granular subbase **Wet Regions**

Subgrade Class	T1 (0.3)	T2 (0.7)	T3 (1.5)	T4 (3)	T5 (6)	T6 (10)	T7 (17)	T8 (30)
	Traffic Class and Traffic Limits (million ESAs)							
S1 2%	SD / 150 / 175 / 300	SD / 150 / 225 / 300	50 / 175 / 200 / 300	50 / 175 / 250 / 300	50 / 200 / 275 / 300	100 / 200 / 225 / 350	125 / 200 / 250 / 350	150 / 200 / 300 / 350
S2 3-4%	SD / 150 / 150 / 200	SD / 150 / 200 / 200	50 / 175 / 175 / 200	50 / 175 / 225 / 200	50 / 200 / 250 / 200	100 / 200 / 225 / 200	125 / 200 / 250 / 200	150 / 200 / 300 / 200
S3 5-7%	SD / 150 / 200	SD / 150 / 250	50 / 175 / 225	50 / 175 / 275	50 / 200 / 300	100 / 200 / 250	125 / 200 / 275	150 / 200 / 325
S4 8-14%	SD / 150 / 125	SD / 150 / 150	50 / 150 / 150	50 / 175 / 175	50 / 200 / 175	100 / 200 / 175	125 / 200 / 200	150 / 200 / 225
S5 15-29%	SD / 200	SD / 200	50 / 150 / 100	50 / 150 / 125	50 / 150 / 150	100 / 150 / 150	125 / 175 / 150	150 / 200 / 150
S6 >30%	SD / 150	SD / 150	50 / 150	50 / 175	50 / 200	100 / 200	125 / 225	150 / 250

gran1w.drw

KEY :-

- Surface dressing or hot mix asphalt as indicated
- Granular Base (Soaked CBR > 80%)
- Granular Subbase (Soaked CBR > 30%)
- Selected layer (Soaked CBR > 15%)

See Appendix A and the Specifications for details

* Code of Practice for the Design of Road Pavements(SATCC) p.C-7

2) Policy on the type of pavement

Based the discussion with the Malawian side during the on-site study and considering the following points, the type of pavement will be asphalt concrete pavement.

- The existing roads leading to the both ends of the project area are asphalt concrete paved (for the sake of continuity).
- Asphalt concrete pavement requires less initial construction cost in comparison with cement concrete pavement (for the sake of economy).
- Asphalt concrete pavement is easier to construct, repair, and renovate in comparison with cement concrete (for the sake of maintenance).

3) Subgrade conditions and incorporation in design

The subgrade in embankment sections will be 100 cm. The CBR of the subbase part will be 12% or more. The subgrade in cut sections will not involve replacement in the existing road pavement parts and the natural ground parts. (According to the condition of the site, exposure of subgrade surfaces comparable to soft rocks is expected to occur even in the sections where natural ground is cut.) Similarly to the embankment sections, CBR in cut sections will be 12% or more.

The following shows the present state of subgrade and design/construction policy in the sections (approximate) along the road.

Table 2-2-29 Present State of Subgrade and Design/Construction Policy

Survey point	Cut/embankment (subgrade thickness)	Remarks
0+0～3+0	Improvement of existing road (0 cm)	Existing pavement slabs are crushed and removed, but replacement is not performed.
3+0～5+0	1 m or more embankment (100 cm)	The section with longitudinal raising from the existing road.
5+0～9+0	Cut and embankment (0 cm/100 cm)	100 cm subgrade construction in embankment areas; no replacement in cut areas.
9+0～11+0	Cut (0 cm)	
11+0～13+0	Cut and embankment (0 cm/100 cm)	100 cm subgrade construction in embankment areas; no replacement in cut areas.
13+0～16+1 （A1）	1 m or more embankment (100 cm)	
South Rukuru Bridge		
19+15～29+0 （A2）	1 m or more embankment (100 cm)	
29+0～35+0	Improvement of existing road (0 cm)	Existing pavement slabs are crushed and removed, but replacement is not performed.

4) Pavement configuration in shoulders and Lay-bys

The pavement configuration in shoulders and lay-bys will be the same as that in the main lanes, considering the possibility that vehicles including large trucks may park in the shoulders and lay-bys as a result of future demands for the international trunk road and the commercial activities along the road.

5) Consideration of slope works

i) Slope gradient

The slope gradient of embankment areas is set at 1:2.0, and the slope gradient of cut areas is set at 1:1.0 for gravelly soil and 1:0.8 for soft rocks. However, if a homogeneous cut slope surface contains a different geological element, cutting will be done using the gentler gradient applicable.

A change of gradient within a slope will not be used.

ii) Slope drainage works

Gutters (concrete bottom and sides; Malawian standard form) will be provided at the toe of embankment slope and toe of cut slope on the side where water discharge from road surface flows.

iii) Slope protection works

Embankment slope surfaces will be treated with protection works using vegetation for the purpose of preventing rain erosion and slope stabilization. Seed sprinkling work will be performed.

While cut slope surfaces are expected to have exposed soft-rock equivalent earth materials, the study of existing cut slopes in the project area indicated the presence of natural vegetation expanding over such surfaces. Therefore, no specific protection works will be used.

Photo 2-2-3 Condition of an Existing Cut Slope Surface

However, if the actual condition of cut slope surfaces indicates rapid progression of weathering and a need for actions against weathering, slope works such as lath mesh plus spraying of growth-supporting material will be considered.

iv) Prevention of inundation at the toes of embankment slopes

For the purpose of protecting the toes of embankment slopes from the flooding of the Lura River, the toes of slopes on the side facing the Lura River (on the left side of the main lanes) from South Rukuru Bridge A2 to No. 26+10 will be protected using concrete block facing works.

The height of the top of block facing works will be 858.70 m, which is the HWL determined from river hydraulic calculation plus a safety margin.

(9) Facility summary

The following Table summarizes the overview of the facilities in this project determined based on the above consideration.

Table 2-2-30 Facility Summary

Item			Type and Specifications
Bridge location			16-19 m downstream from existing Rukuru Bridge
Width	Bridge		Carriageway width 3.35m×2=6.7m, bicycles 0.3m×2=0.6m, sidewalk width 1.2m×2=2.4m; total 9.7m (effective width) Curb 0.4m×2=0.8m Total 10.5m (total width)
	Access road		Carriageway width 3.35m×2=6.7m, bicycles 0.3m×2=0.6m, sidewalk width 1.2m×2=2.4m; total 9.7m (effective width) Protective shoulders 1.0m×2=2.0m Total 11.7m (total width)
Bridge type			Two-span connected PCT girder bridge
Bridge length, span configuration			37.0m＋37.0m＝74.0m
Pavement of bridge surface			Asphalt pavement (carriageway 50mm)
A1 abutment (Mzuzu side)	Type		Inverted T-type abutment
	Structural height		12.0m
	Foundation		Spread foundation
A2 abutment (Karonga side)	Type		Inverted T-type abutment
	Structural height		12.0m
	Foundation		Spread foundation
P1 pier	Type		Oval-shaped
	Structural height		P1=10.2m
	Foundation		Spread foundation
Access road	Length		Right bank: 321m, Left bank: 305m
	Pavement		Asphalt pavement (surface 50mm)
Bank protection works	South Rukuru River	Right bank	Concrete-filled masonry 1360m2 Wire mattress gabion 285m2
		Left bank	Concrete-filled masonry 1465m2 Wire mattress gabion 435m2
	Lura River	Left bank	Concrete-filled masonry 547m2 Wire mattress gabion 120m2
Riverbed protection works	South Rukuru River	Right bank	Stone-faced concrete blocks 545m2
		Left bank	Stone-faced concrete blocks 603m2
	Lura River	Left bank	Stone-faced concrete blocks 416m2
	P1 pier		Concrete 105m3

2-2-3 Outline Design Drawing

The outline design drawings prepared according to the above basic plan are presented in the following pages.

- Fig. 2-2-31 Plan of Access Road
- Fig. 2-2-32 Profile of Access Road
- Fig. 2-2-33 Standard Cross-section
- Fig. 2-2-34 General Drawing of South Rukuru Bridge
- Fig. 2-2-35 Plan of Revetment