CHAPTER 12 ALTERNATIVE STUDIES

12.1 Alternative Routes and Selection of Routes

12.1.1 Alternative Routes

There are three possible alternative routes for planning the bridge connecting Botswana and Zambia across the Zambezi River to replace the existing ferry connection. Shown on Figure 12.1.1, these are:

(1) Route A

On the Zambian side, the route extends from the existing approach road and passes near the estuary on the left bank. It then traverses the river, the major area of concern being near the right bank immediately downstream of the confluence of the Zambezi and Chobe Rivers where there is some hydraulic variability in the flow regime. During construction of the bridge, it is necessary that the existing ferry remains operational. The bridge length of this alignment is comparatively long.

(2) Route B

The route is situated immediately upstream of the existing ferry line. On the Botswana side, this coincides with the existing ferry on-ramp. During bridge construction, ferry operation is therefore likely to be affected. Again, the bridge length of this alignment is comparatively long.

(3) Route C

The route is parallel with the transmission line and coincides with the existing ferry on-ramps on both riverbanks. The route does not maintain a right angle with river flow direction, as is normally desirable for bridge alignment. The route distance is shorter than other alternatives. During construction of the bridge, ferry operation must use the more upstream of the two existing on-ramps with associated slope improvements.

12.1.2 Selection of Route

The following factors were considered in selecting the most suitable route for bridge planning:

(1) Minimizing costs for the bridge construction, especially for the works within the river channel

(2) Minimizing influence on both existing ferry operation and procedures for customs and immigration

(3) Minimizing disturbance to the existing facilities such as military barracks, market square and transmission line

(4) Avoiding serious hydraulic issues in the river, especially those associated with the complex junction of the Zambezi and Chobe Rivers

(5) Selecting a suitable location in terms of geotechnical conditions (depth to resistant basalt rock)

(6) Selecting a suitable location in terms of international boundaries recognition

A summary of these factors is presented for each route in Table 12.1.1. Route C is considered the most economic due to its shorter alignment and reduced technical problems such as hydraulic issues, notwithstanding the requirements for onshore ramp improvement. This route is therefore recommended as the most suitable bridge crossing for the Zambezi River.

Figure 12.1.1 Location of Alternative Routes

Table12.1.1 Evaluation for Route Selection

Alternative Route	a) River water surface to be affected cost	b) Influence on ferry operation	c) Influence on existing facilities	d) Disturbance to transmission line/tower	e) Hydrodynamic issues	f) International boundaries
1) Route- A	• Due to the upstream location and crossing of estuary of tributary, the river crossing length is longer than Route B & C.	•Since location is further from the existing ferry line, it does not affect ferry operation.	•It does not affect the customs and immigration post and Botswana's military barracks.	• No disturbance to the power transmission line.	•Hydrodynamic issues therefore must be cautious, especially at the confluence of two rivers.	•Close to the Namibia side in the river, and crossing Botswana and Zambia.
	D	⦿	**O**	**O**	**D**	**D**
2) Route - B	• Due to the upstream location and crossing of estuary of tributary, the river crossing length is longer than Route C.	•Even though located upstream of ferry line, it may slightly affect the ferry operation.	•It does not affect the customs and immigration post, and Botswana's military barracks.	•No disturbance to the power transmission line.	•Hydrodynamic issues therefore must be cautious, especially at the confluence of two rivers.	•Crossing Botswana and Zambia.
	O	**O**	**O**	**O**	**O**	**O**
3) Route - C	•Crossing the river along the transmission line alignment is shorter length than other alternatives.	•The location is same as the existing ferry line. The ferry operation must be shifted to the upstream side.	•It does not affect the existing facilities as for other alternative Routes.	•No disturbance in keeping restricted distance from transmission line.	• Rather less hydrodynamic issues compared to other routes.	•Crossing Botswana and Zambia, and close to the Zimbabwe border.
	⦿	**D**	**D**	**O**	⦿	**O**

⦿: Most satisfactory compared to other routes **O**: Satisfactory for bridge planning **D**: Technical or economic solutions needed

12.2 Alternative Bridge Type and Selection of Bridge Type

12.2.1 Bridge Span Length and Bridge Opening

In assessing possible bridge types including approach span bridges to cross the Zambezi River, the following factors were considered and Figure 12.2.1 shows the selection process of the bridge type.

- Minimum bridge span length
- Hydrological condition of the river
- Bridge opening (total bridge length)
- Constriction to the river water flow

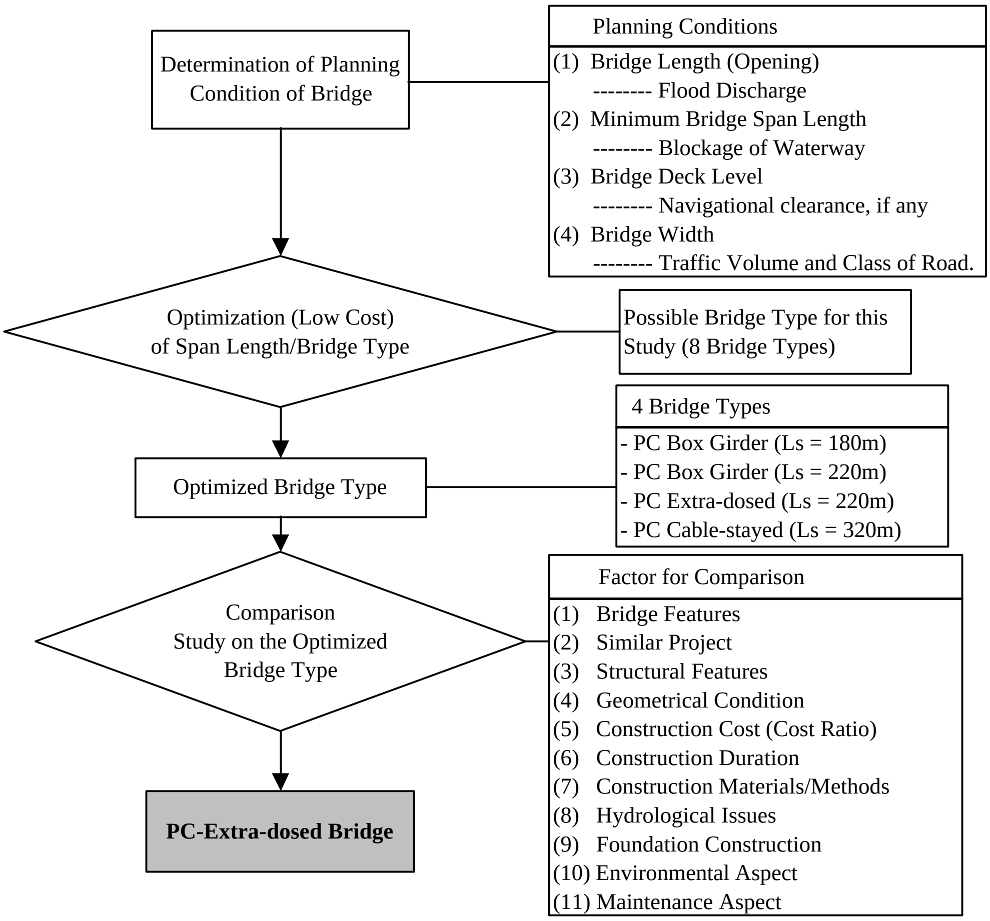


Figure 12.2.1 Selection of Bridge Type

(1) Minimum bridge span length

Minimum bridge span length is one of the basic hydraulic requirements in assessing the bridge structures to be constructed over the river. To avoid blockage of waterway due to accumulation of logs and other debris, a desirable bridge span length should be maintained. The following equation has been established by of Japanese Ministry of Construction to determine the minimum requirement for the length between piers.

$$L = 20 + 0.005\,Q$$

where

L = desirable minimum bridge span length (m)

Q = design discharge (m^3/s).

If design discharge is 10,000 m^3/s (comparable to the 100 year design flood outlined in Chapter 5), the required minimum bridge span length is 70m.

(2) Bridge Opening

Bridge opening refers to total bridge length to meet hydraulic requirements and to avoid wash-out behind the bridge abutment, overtopping of the approach road and local and general scouring of the riverbed due to insufficient bridge opening, that is excessive constriction. The river width directly related to bridge opening can be determined from the following diagram (Figure 12.2.2) which defines the relationship between design river width and discharge. The design discharge will be determined based on the hydrological analyses as described in Chapter 5. Based on these results, the required bridge opening (total bridge length) is around 800 m, however, this requires further economic and technical considerations.

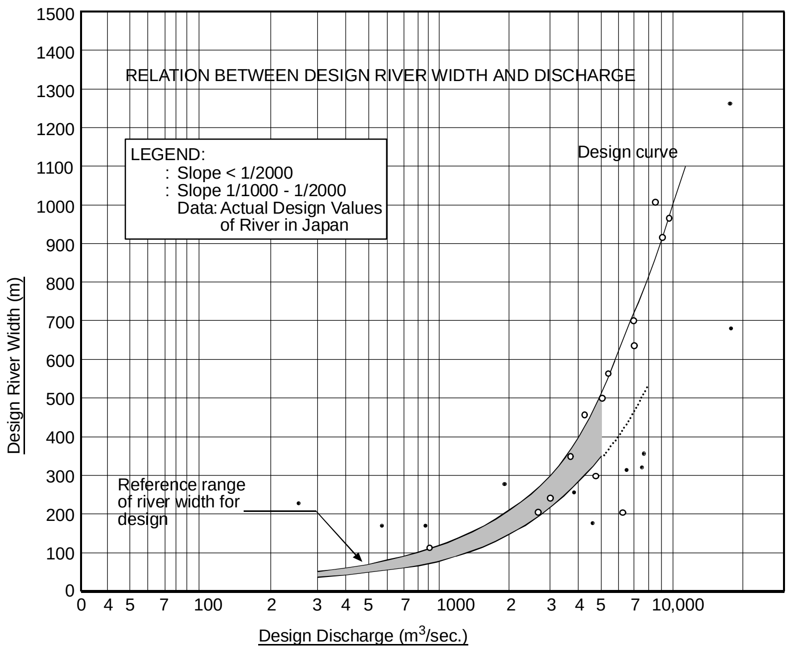


Figure 12.2.2 Design Discharge and Bridge Opening

(3) Hydrological Condition of the River

The bridge site is located immediately downstream of the confluence of the Zambezi and Chobe Rivers. The riverbed will change during large floods, particularly due to scour of the weathered sections of the underlying basalt rock. From this viewpoint, it is desirable that the bridge span straddle the changeable and deep riverbed (as shown in Figure 12.2.3), thus avoiding the hydrodynamic (hydraulic) issues. The latter will occur predominantly near the right riverbank, where the riverbed is significantly affected by discharge of the Chobe River flow.

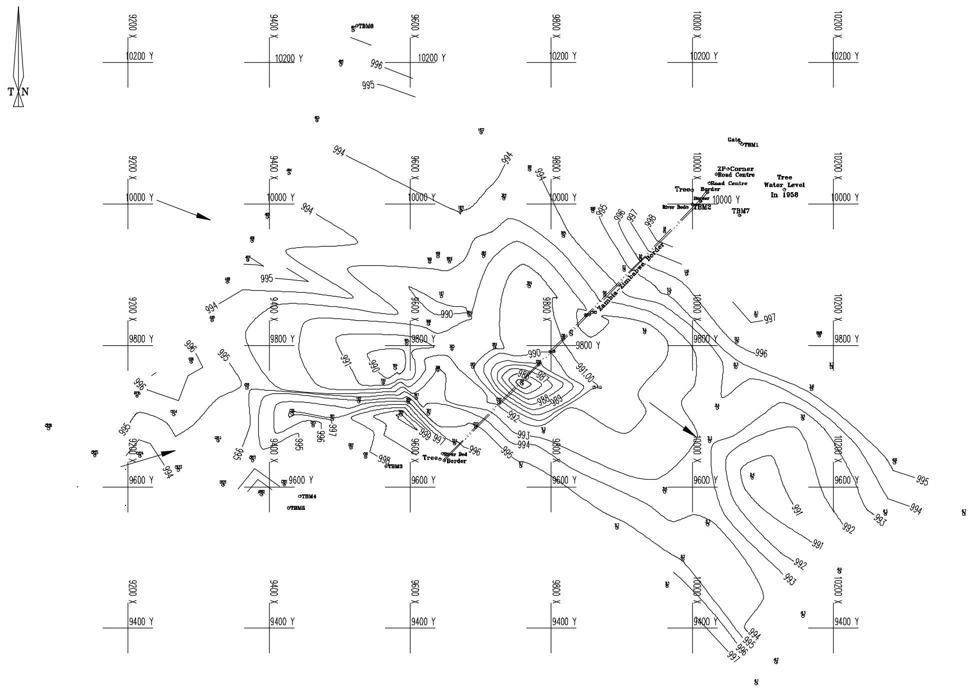


Figure 12.2.3 Riverbed Contour Map by Bathymetric Survey (October 1999)

(4) Constriction of the River Flow

Detailed considerations on constriction of river flow require more complex hydraulic assessments such as physical model testing or computer simulation. It is, however, proposed to use a constriction ratio for preliminary evaluation, this being defined as the ratio of disturbed areas by the bridge piers against the total bridge opening. The constriction ratio normally considered appropriate for bridge design is between 0.03 and 0.07. The effective bridge opening and disturbance area must be measured at right angles to the principal direction of the river and not along the center-line of the bridge in the case of a skewed bridge.

12.2.2 Possible Bridge Types and Selection of Bridge Type

(1) Possible Bridge Type

The possible bridge types considered for the Kazungula Bridge are shown in Figure 12.2.4, considering the minimum required span length (70 m) and the hydrological conditions at the site as discussed above.

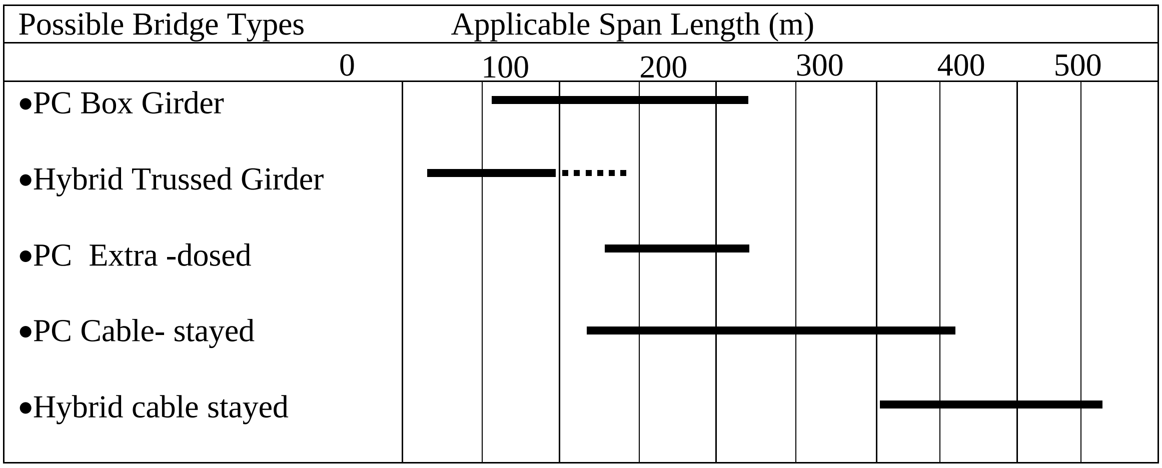


Figure 12.2.4 Relationships between Bridge Types and Applicable Span Length

(2) Selection of Bridge Types

From the possible bridge types, the following eight types were considered for crossing the Zambezi River. The river channel width varies from around 400m to 800 m based on the results of the hydrologic studies (see Chapter 6). Either side of the main bridge section, the viaduct bridges were designed as approach spans to the main bridge.

a) PC Box Girder (L_s =95m)
b) Hybrid Trussed Girder (L_s =95)
c) PC Box Girder (L_s = 185m)
d) PC Box Girder (L_s=185m)
e) PC Box Girder (L_s =240m)
f) PC Extra-dosed (L_s =240m)
g) PC Cable – Stayed (L_s = 320m)
h) Hybrid PC Cable –stayed (L_s =450m)

where
L_s = span length (m), PC: Prestressed Concrete

12.2.3 Optimised Span Length and Bridge Type for the Main Bridge

To optimize the bridge type in accordance with span length, preliminary costs of the bridge construction in combination with superstructure and substructure and foundations were calculated. The construction cost for each bridge type is presented by construction cost ratio as shown in the Figure 12.2.5. Initially, cost comparison was based on the total bridge length of 800 m. Subsequently the comparison was based on the main bridge length of 480 m.

In this figure, desirable bridge span length ranged from 200m to 240m. The shorter span length requires multi-piers which are costly due to the necessity of foundation construction in deep water with high flow velocities during the flooding. In addition to span length, further consideration should, however, also be given to avoiding the hydrodynamic issues at the confluence point of the Zambezi and Chobe Rivers should be made.

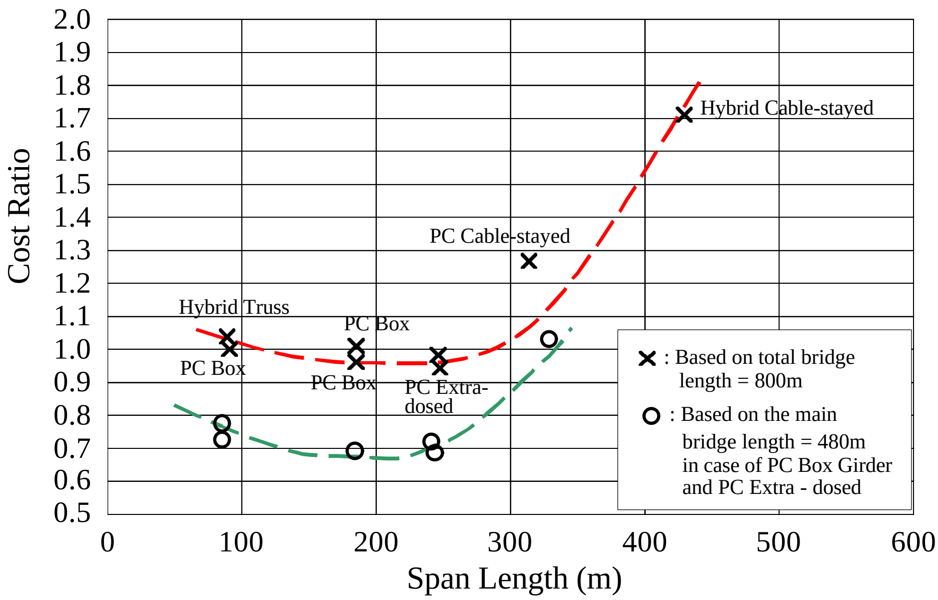


Figure 12.2.5 Construction Cost Ratio in Accordance with Span Length

For the span arrangement, PC Box Girder and PC Extra-dosed bridge types were much more suitable economically. The PC Box Girder is not, however, recommended due to its deep girder depth (approximately 12m) above the high flood level at the supporting point. This would require a high bridge deck level and heavier concrete section of the girder, significantly influencing the substructure and foundations of the piers. For the final decision on the main bridge type, PC Box Girder and PC Extra-dosed types will be examined in detail from both the economic viewpoint and approach road design.

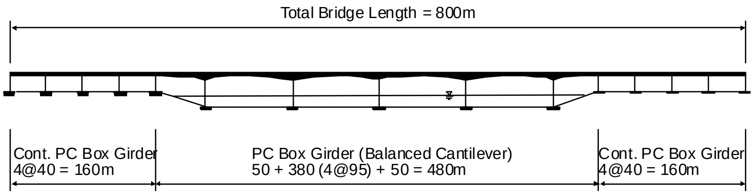
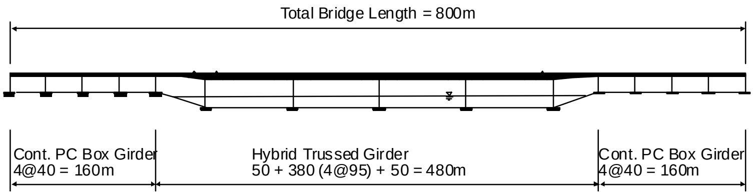
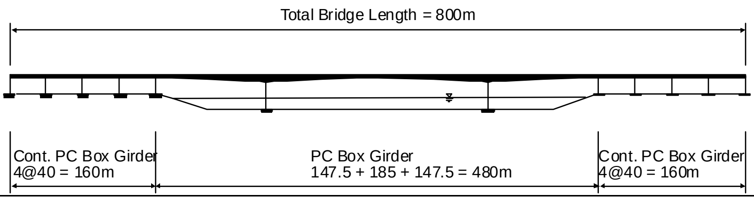
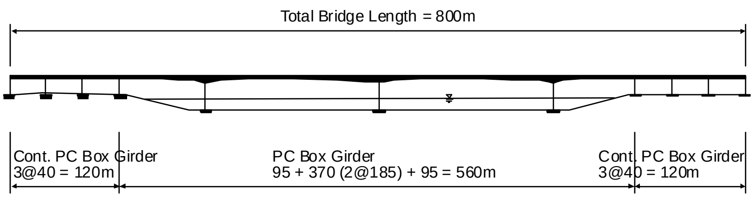
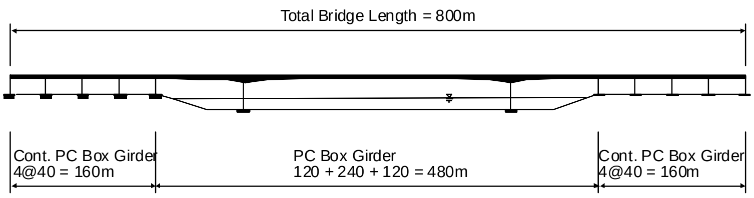
Image of Bridge Types	Bridge Features
(1) PC – Box Girder (Ls = 95m) 	• Superstructure is comparatively economic because of shorter span length (Ls =95m). However, the number of pier locations in the river will total 5, which requires costly false work such as temporary jetty and cofferdams. • Construction cost ratio : 1.000
(2) Hybrid Trussed Girder (Ls = 95m) 	• Since the main girder is composed of steel pipes and concrete decks, the superstructure weight is lighter, resulting in lower dead loads being transmitted to the substructure. Less concrete works will reduce the construction time. • Construction cost ratio : 1.037
(3) PC- Box Girder (Ls =185m) 	• The depth of the box girder varies. The deepest point is 9m. The number of pier locations in the river is 2. • Construction cost ratio: 0.976
(4) PC – Box Girder (Ls = 185m) 	• The depth of the box girder varies. The deepest point is 10m. The number of pier locations in the river is 3. • Construction cost ratio: 1.049
(5) PC-Box Girder (L_s =240m) 	• The depth of the girder varies. The deepest point is 14m. This more accentuated depth may raise the proposed elevation of the bridge deck due to the clearance requirement from the flood water level. The number of the pier locations in the river is 2. • Construction cost ratio: 0.984

Figure 12.2.6 Selection of Bridge Type (1/2)

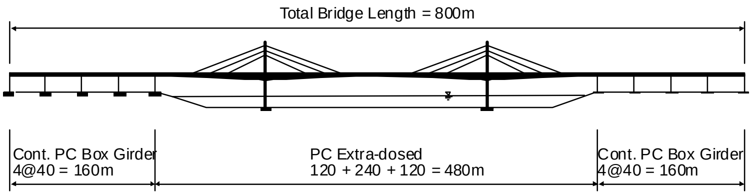
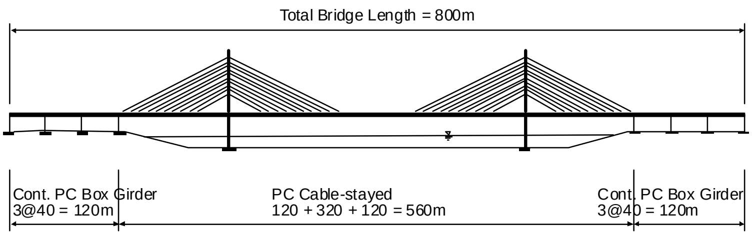
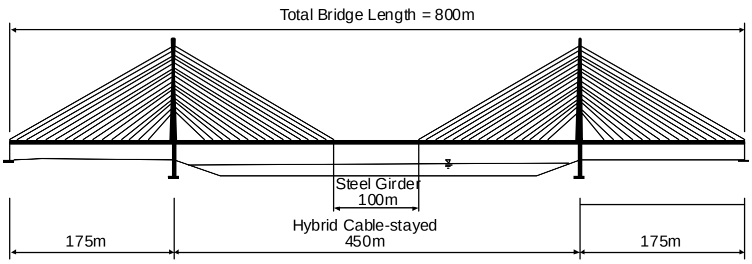
Image of Bridge Types	Bridge Features
(6) PC- Extra -dosed (L_s = 240m)  	• The structural function is between PC-Box Girder and PC Cable-stayed Bridges, accordingly applicable span length also between them. The external cable enables the girder depth to be shallow. The shallow girder depth is advantageous to the substructures. The projected pylons are disadvantageous in case of collision by heavy and longer body of trailer trucks. • Construction cost ratio: 0.975
(7) PC – Cable-Stayed (L_s = 320m)  	• The stay cable enable a shallow girder depth by lifting force in the vertical direction. Because of this shallower girder depth, it is greatly beneficial in terms of aesthetics. Aerodynamic stability should be examined because of cable system structure. Disadvantage of pylons by the trailer truck is same as for others with projected pylons. • Construction cost ratio: 1.269
(8) Hybrid (PC + Steel) Cable-Stayed  	• The span length of 450m is able to straddle the river channel (at low flow levels) with a single span. The bridge structures will be free from hydrodynamic issues. High pylons and multi-cables require costly construction. • Construction cost ratio: 1.713

Figure 12.2.6 Selection of Bridge Type (2/2)

Table 12.2.1 Comparison Study of Alternative Bridge Types

Alternative Bridge Types	**a) Economical Aspect Construction Cost Ratio**	**b) Hydraulic Issues around piers .**	**c) Construction Method and Material.**	**d) Construction Period.**	**e) Maintenance Aspect**	**f) Clearance to Food Water**	**g) Aesthetic Aspect.**
(1) PC-Box Girder (L_s = 95m)	1.000	• Hydraulic problems due to many piers (5 locations) in the river during flood season	• Easier material procurement of superstructure • More problems with pier construction in the river	• Comparatively long (42 months)	• Less Maintenance	• Comparative problem due to girder depth	• Not impressive
(2) Hybrid Trussed Girder (L_s = 95m)	1.037	• Hydraulic problems same as alternative 1)	• Require imported material of steel. • Less concrete work for superstructure	• Comparatively short (36 months)	• Maintenance required	• Comparative problem due to girder depth	• Not impressive
(3) PC-Box Girder (L_s = 185m)	0.976	• Reduced hydraulic problems because of longer central span	• Easier material procurement • Typical balanced cantilever method of superstructure	• Normal (39 months)	• Less Maintenance	• Comparative problem due to deep girder raising the bridge deck	• Not impressive
(4) PC-Box Girder (L_s = 185m)	1.049	• Hydraulic problems due to a pier in the middle of river during flood season	• Easier material procurement • Typical balanced cantilever method of superstructure	• Comparatively long due to the central pier (42 months)	• Less Maintenance	• Comparative problem due to deep girder raising the bridge deck	• Not Impressive
(5) PC-Box Girder (L_s = 240m)	0.984	• Reduced hydraulic problems because of longer central span	• Less problems due to flood water for the foundation construction • Require comparatively skilled construction	• Normal (39 months)	• Less Maintenance	• Comparative problem due to deep girder raising the bridge deck	• Not Impressive

Note: 1) L_s = Span Length of Main Girder

2) Months for Construction Period are subject to further study

(continued)

Alternative Bridge Types	a) Economical Aspect Construction Cost Ratio	b) Hydraulic Issues around piers .	c) Construction Method and Material.	d) Construction Period.	e) Maintenance Aspect	f) Clearance to Food Water	g) Aesthetic Aspect.
(6) PC-Extra dosed (L_s = 240m)	0.975	• Less hydraulic problems of longer central span	• Reduced problems due to flood water for the foundation construction • Requires skill for the girder construction	• Normal (39 months)	• Maintenance required	• No problem because of the comparatively shallow girder depth	• Symbolic
(7) PC – Cable Stayed (L_s = 320m)	1.269	• No hydraulic problems because of pier location near riverbank	• Reduced problems due to flood water for the foundation construction. • Requires skill for the cable and girder construction.	• Comparatively long (42 months)	• More maintenance required	• No problem because of the shallow girder depth.	• Very symbolic
(8) Hybrid (PC + Steel) Cable-stayed (L_s = 450m)	1.713	• No hydraulic problems because of pier location on the riverbank	• No problem due to flood water • Requires sophisticated technology for the super-structures.	• Long (46 months)	• More maintenance required	• No problem because of the comparatively shallow girder depth.	• Very symbolic

Note: 1) L_s = Span Length of Main Bridge

2) Months for Construction Period are subject to further study.

Classified Rating	Alternative Bridge type	a)	b)	c)	d)	e)	f)	g)
⊙ : Excellent	(1) PC Box Girder	**D**	**X**	**X**	**X**	**O**	**D**	**X**
	(2) Hybrid Trussed	**D**	**X**	**X**	⊙	**D**	**D**	**X**
O : Good	(3) PC – Box Girder	**O**	**D**	**O**	**O**	**O**	**O**	**D**
	(4) PC – Box Girder	**D**	**X**	**O**	**D**	**O**	**X**	**D**
D : Fair	(5) PC – Box Girder	**O**	**O**	**O**	**O**	**O**	**X**	**D**
	(6) PC- Extra dosed	⊙	**O**	**O**	**O**	**D**	⊙	**O**
X : Worse or Problem	(7) PC Cable-stayed	**X**	⊙	**D**	**X**	**X**	⊙	⊙
	(8) Hybrid Cable stayed	**X**	⊙	**X**	**X**	**X**	⊙	⊙

12.2.4 Further Examination of Bridge Types

Mainly from the economical reason, the three bridge types from PC Box Girder and PC Extra-dosed were selected for the further examination from the technical and economical viewpoints. In this further examination stage the total bridge length of 720 m and the required central span length of 180 m and 220 m were considered based on the hydrological and hydraulic survey and analysis in Chapter 6.

(1) Total Bridge Length

The total bridge length that is related to the waterway opening width which is able to provide the solution to avoid hydro dynamic issues such as wash-cut behind bridge abutment, overtopping of approach roads and scouring of the riverbed. The required bridge openings which are ordinary estimated by the empirical formula such as Lacy's formula, a systematic graph relating between river width and design discharge and the past flood records. As the basic condition for the comparative study of bridge types, the waterway opening width of 800m, based on the empirical relationship between discharge and bridge opening, was considered. For the preliminary design, the following results of hydrological analysis and flood records are to be reflected:

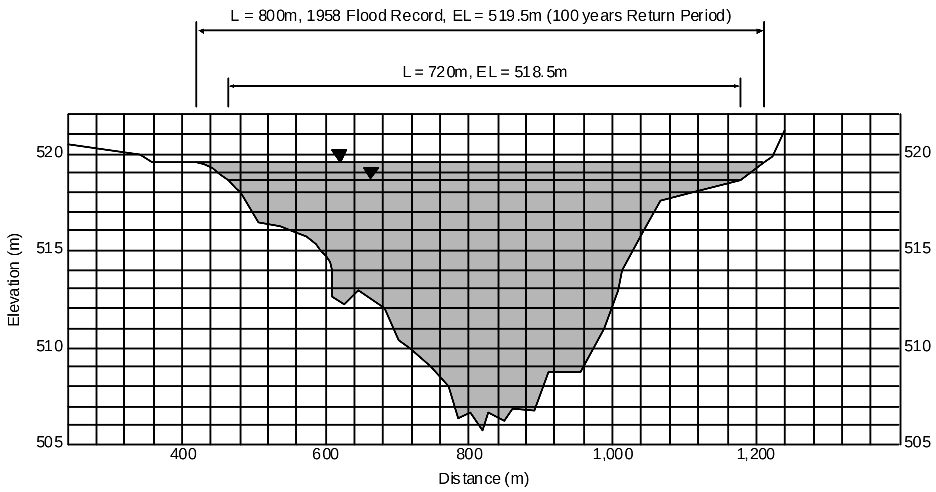


Figure 12.2.7 Waterway Opening Width and Elevations based on the 1999 October survey

The waterway opening width (waterway surface) in 1958 flood (equivalent to 100-year flood) was 800 m, the design bridge opening (bridge length) can be determined as 720 m to economise the bridge length without hydrodynamic issues of the road embankment behind them.

(2) Central Span Length

To determine the design central span length of the main bridge in addition to the economical optimisation related to the bridge types, the following conditions were examined further from the technical and economical viewpoints.

Conditions to be examined	Central span length of main Bridge (m)			
	185	200	220	240
a) Height from the girder soffit of temporary bridge (at the water level of 50 years) to the riverbed at the pier	9.5 m (7.5 m) ×	8.5 m (6.5 m) Δ	8.0 m (6.0 m) O	7.5 m (5.5m) O
b) Flow velocity at the piers of central span under 100 year flood	2.4 m/sec. Δ	2.3 m/sec. O	2.3 m/sec. O	2.2 m/sec. O
c) Total length of temporary bridge from each river side	535 m ×	520 m Δ	500 m O	480 m O
d) Cost ratio of temporary bridge	1.11 ×	1.08 Δ	1.04 O	1.00 O

Note: Figures within bracket are height below the average water level.
O: Typically applicable
Δ: Applicable with observation
×: Not recommendable

The central span length of 240 m is advantageous in costing for the construction of the temporary bridge works; however, the central span length of the main bridge is the longest for the similar bridge type of cable system (internal and external) which will necessitate the solutions on fatigue capacity and pouring concrete method, etc. Therefore, a central span length of 220 m was recommended.

(3) Further Examination

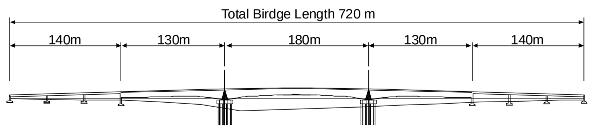
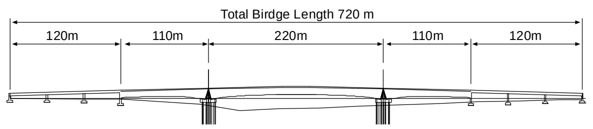
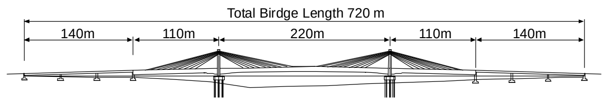
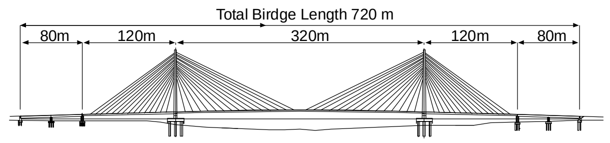
In the further examination stage, the following factors were compared for each alternative bridge type.

- Bridge Features
- Similar Project
- Structural Features
- Geometrical Condition
- Construction Cost (Cost Ratio)
- Construction Duration
- Construction Method/Materials
- Hydrological Issues
- Foundation Construction
- Environmental Aspect

Consequently, PC-Box Girder (Ls=180 m) was not recommended due to huge and complicated concrete works at the supporting point, and because the narrow central span is risky for temporary and permanent works of the foundations during the flood season compared with the other alternatives. PC-

Box Girder (Ls=220m) was not recommended due to the huge concrete works as for the previous alternative (A), which will affect the construction of foundation works, cost and construction duration. PC Extra-dosed (Ls=220m) type was recommended for the reasons of superiority in construction cost, vertical gradient, concrete works and symbolic appearance.

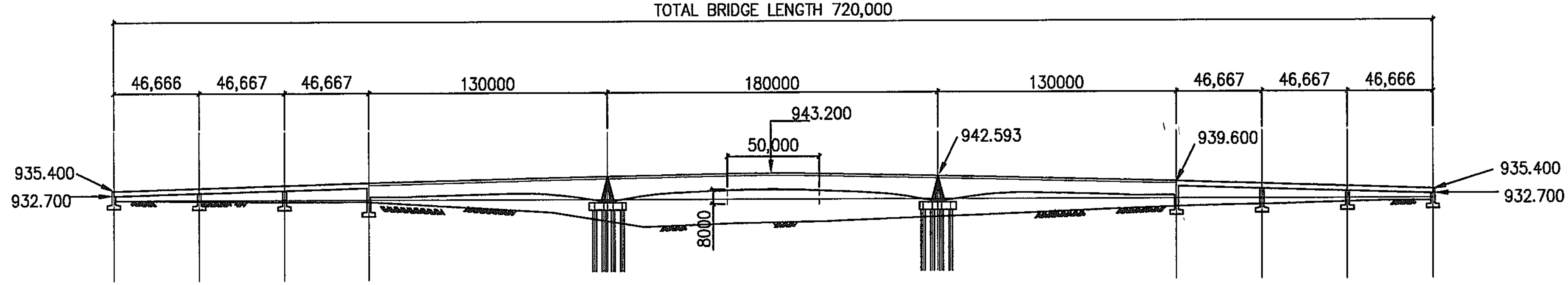
Table 12.2.2 Comparison Study of Bridge Type

Alternative Bridge Type	(A) PC – Box Girder (Ls = 180m)	(B) PC – Box Girder (Ls =220m)	(C) PC – Extra – dosed (Ls = 220m)	(D) PC Cable-stayed Bridge (Ls = 320m)
(1) Bridge Features				
(2) Similar Project	• Akigawa Ohashi (220m, 1985) • Urato Ohashi (230m, 1972) ○	• Hikoshima Ohashi (236m, 1975) • Hamana Ohashi (240m, 1976) ○	• 2nd Mactan Bridge (185m, 1999) • Tsukuhara Bridge (180m, 1997) • Tobuyama Bridge (220m, 2000, Detailed Design stage) ○	• Brotonme Bridge (320m, 1977, France) • Pasco-Kennewick (300m, 1978, USA) • Talmage Memorial Bridge (335m, 1990, USA) ○
(3) Structural Features	• Main girder depth varies and 9m at the supporting point and 3.5 at the middle of central span. • Prestressing Tendons are inner cable system in the box girder concrete, therefore, prestressing force will be limited. △	• Main girder depth varies and 13m at the supporting point and 4.0 at the middle of central span. • Prestressing Tendons are inner cable system in the box girder concrete, therefore, prestressing force will be limited. △	• Main girder depths are 6.0m at the supporting point and 3.0 at the middle of central span. • Prestressing cables are external system and outside of the box girder concrete. It is able to hold greater eccentric distance for prestressing force. ○	• Main girder depths are 3.6m at the supporting point and 2.5m at the middle of central span, and pylon height is 70m. • Longer stay cables are disadvantage for aerodynamic stability. △
(4) Geometrical Condition	• Bridge deck level is controlled by design high flood water level and deck level is between (B) and (C). • Vertical gradient is 3% and road embankment height is 5m at the bridge abutment. △	• Bridge deck level is controlled by design high flood water level, and highest level among the alternatives. • Vertical gradient is 3% and road embankment is 5m at the bridge abutment. ×	• Bridge deck level is controlled by navigational clearance, and lowest level among the alternatives. • Vertical gradient is 2.5% and road embankment is 5m at the bridge abutment. ○	• Bridge deck controlled by navigational clearance, and lowest level. • Vertical gradient is about 2.0% and road embankment is 4m at the bridge abutment. ○
(5) Construction Cost (Cost Ratio)	• Cost Ratio = 1.00 ○	• Cost Ratio = 1.06 △	• Cost Ratio = 0.90 ◎	• Cost Ratio = 1.30 ×
(6) Construction Duration	• Comparatively long duration (42 – month) △	• Comparatively long duration (42-month) △	• Normal duration (39-month) ○	• Comparatively long duration (42 – month) △
(7) Construction Method/ Materials	• Coarse and fine aggregate are available from the quarry site (within approx. 60km) in Zambia. • Re-bars and prestressing tendons are to be imported. • Large volume (approx. 16,600 cu.m for girder) of concrete is required, which causes difficult works in pouring concrete especially for deep girder at supporting point. △	• Coarse and fine aggregate are available from the quarry site (within approx. 60km). • Re-bars and prestressing tendons are to be imported. • Large volume (approx. 21,000 cu.m for girder) of concrete is required, which causes hard works in pouring concrete especially for deep girder at supporting point. ×	• Availability of coarse and fine aggregate is same condition as alternative (A) and (B). • Re-bars and prestressing tendons and stay cables are to be imported. • Concrete volume for girder is approx. 14,000 cu.m and small than (A) and (B). △	• Availability of coarse and fine aggregate is same condition as other alternative. • Re-bars and stay cables are imported, especially large quantity of stay cables is to be needed. • Lesser concrete work compared with Alternative (C). △
(8) Hydrological Issues	• Shorter central span length compared with (B) and (C) is disadvantageous to hydrological issues around the piers in the river. ×	• More advantageous than (A) to hydrological issues around the piers in the river. ○	• More advantageous circumstance than (A) in hydrological issues around the piers in the river. ○	• Most advantageous in hydraulic issues around the piers in the river. ◎
(9) Foundation Construction	• Shorter central span length involves rather difficult work for the foundations in the river, and require longer temporary bridge. • Heavy weight of concrete affects foundation structure. Concrete weight ratio: 1.2. ×	• Longer span length allows less problems on the temporary bridge during flooding. • Heavy weight of concrete affects foundation structure. Concrete weight ratio: 1.5. △	• Longer span length allows less problems on the temporary bridge as (B). • Concrete weight is rather small compared with (A) and (B). Concrete weight ratio: 1.0. ○	• Less problems on temporary bridge during construction. • Lesser concrete weight is less influence to the foundations. ○
(10) Environmental & Aesthetic Aspect	• Ponderous view is worse due to excessive weighty, therefore aesthetic aspect is disadvantageous. △	• Ponderous view is worse due to excessive weighty, therefore aesthetic aspect is disadvantageous. △	• Pylon height (22m) slightly affect to the view of symbolic view. • Pylon is symbolic appearance, and its lower structure is harmonized with surrounding natural circumstances. ○	• Pylon height (70m) much affect to the natural circumstances (abrupt projection). • Pylon is symbolic appearance, but its higher structure is not harmonized with surrounding natural circumstances. △
(11) Maintenance Aspect	• Lesser structural problems such as concrete cracks and corrosion of steel materials. ○	• Concrete cracks due to heavier and longer central span length, slightly risky in corrosion of steel in terms of maintenance. △	• Due to cable system structure, slightly riskey in terms of maintenance aspect Atmospheric circumstance, however, is good. △	• Due to longer stay cables risky in terms of maintenance aspect (more potential of cable vibration). △
Overall Rating	**Not recommendable** due to huge concrete works and complicated concrete works at the supporting point. Narrow central span length is risky temporary works for the foundation during the flood season.	**Not recommendable** due to huge concrete works and complicated concrete works at the supporting points which will affect to the construction of foundation works, cost and period (longer).	**Recommended** from the reasons for superiority in construction cost, vertical gradient, concrete works and symbolic appearance.	**Not recommendable** due to high construction cost and negative structural features such as high pylons and long stay cables.

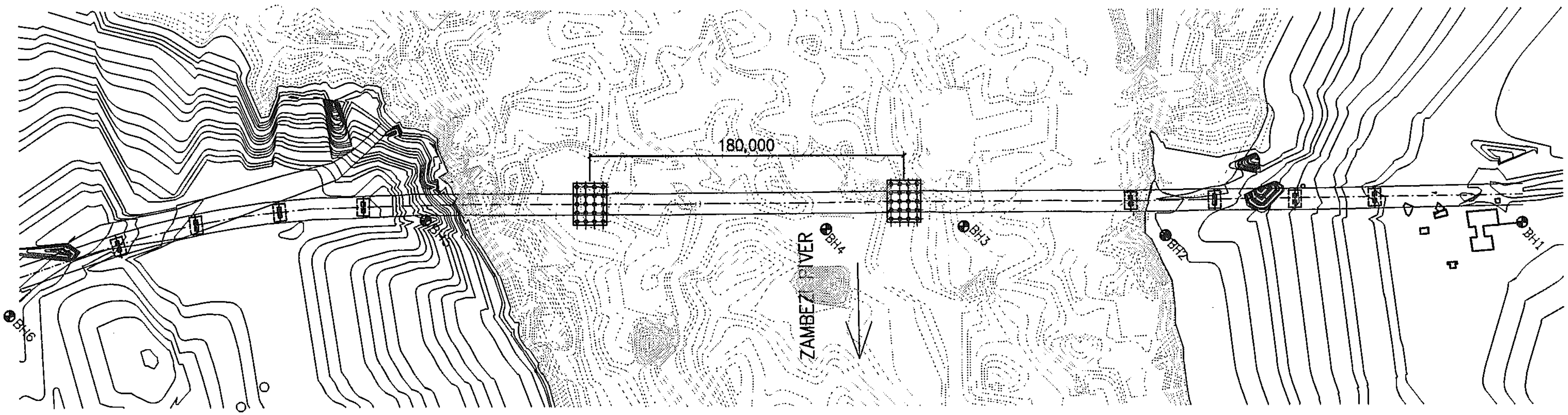
Note: ◎: Excellent ○: Good △: Fair X: Worse

The months for the construction duration are subject to further estimation.

(5) Construction costs include the approach roads.



PROFILE



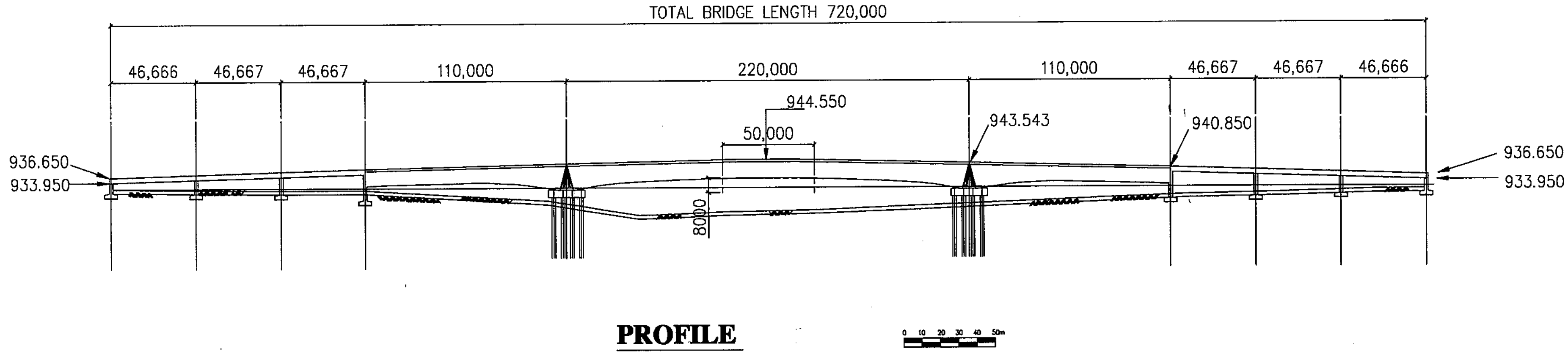
BOTSWANA

PLAN VIEW

ZAMBIA

Figure 12.2.8 General View of PC-Box Girder (Ls=180m)

PROJECT NAME	IMPLEMENTATION AGENCY	EXECUTING AGENCY	JICA STUDY TEAM	DRAWING TITLE	DWG NO.
THE FEASIBILITY STUDY ON THE PROPOSED KAZUNGULA BRIDGE OVER THE ZAMBEZI RIVER BETWEEN BOTSWANA AND ZAMBIA	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	MINISTRY OF WORKS, TRANSPORT AND COMMUNICATIONS REPUBLIC OF BOTSWANA MINISTRY OF WORKS AND SUPPLY REPUBLIC OF ZAMBIA	NIPPON KOEI CO.,LTD. ORIENTAL CONSULTANTS CO.,LTD	General View of PC-Box Girder (Ls=180m)	



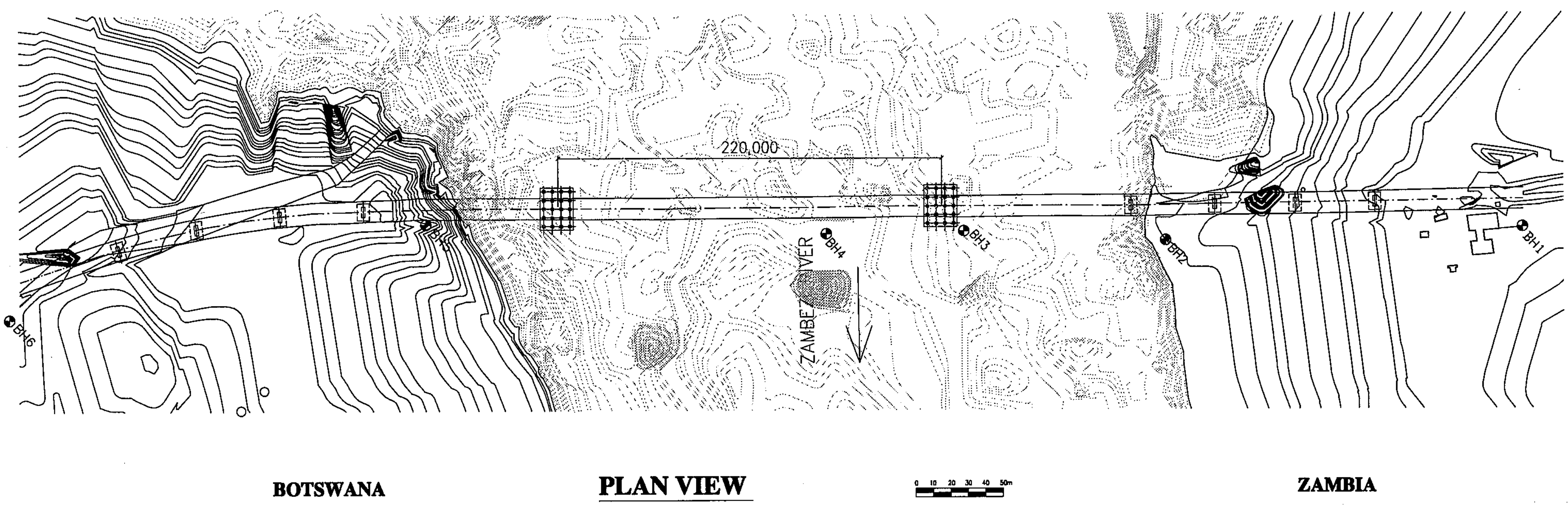
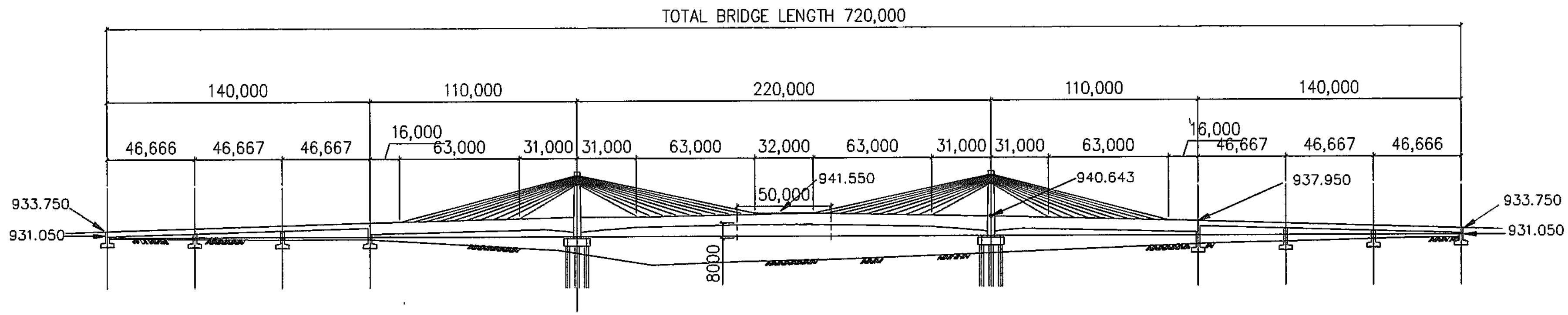


Figure 12.2.9 General View of PC-Box Girder (Ls=220m)

PROJECT NAME	IMPLEMENTATION AGENCY	EXECUTING AGENCY	JICA STUDY TEAM	DRAWING TITLE	DWG NO.
THE FEASIBILITY STUDY ON THE PROPOSED KAZUNGULA BRIDGE OVER THE ZAMBEZI RIVER BETWEEN BOTSWANA AND ZAMBIA	JICA JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	MINISTRY OF WORKS, TRANSPORT AND COMMUNICATIONS REPUBLIC OF BOTSWANA MINISTRY OF WORKS AND SUPPLY REPUBLIC OF ZAMBIA	NIPPON KOEI CO.,LTD. ORIENTAL CONSULTANTS CO.,LTD	General View of PC-Box Girder (Ls=220m)	



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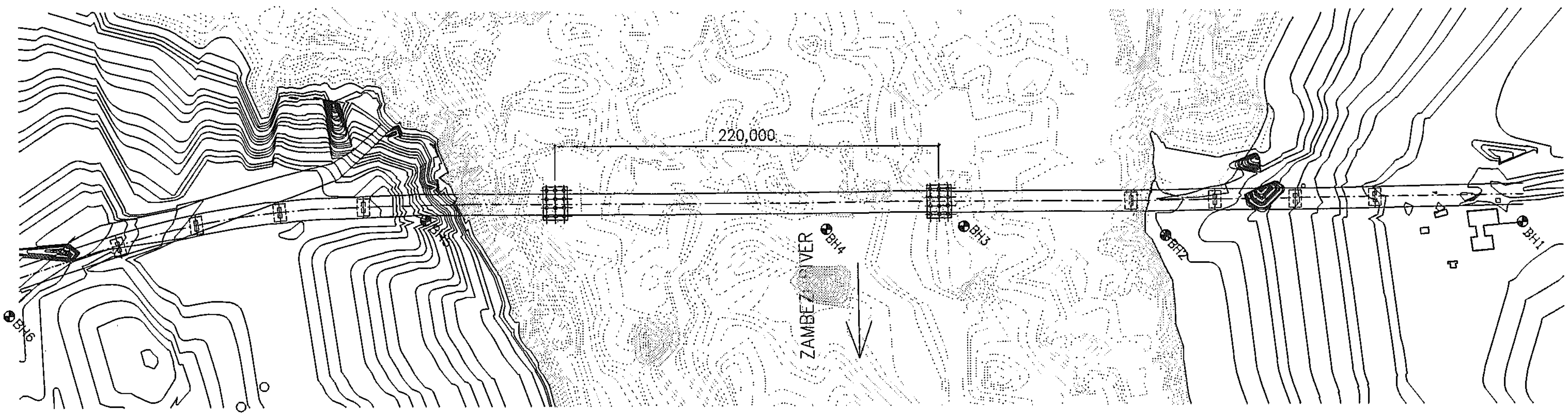
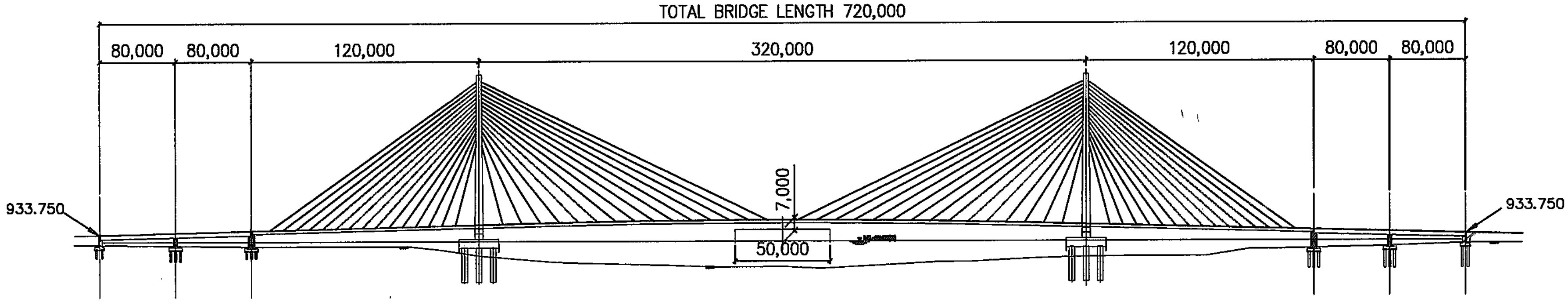


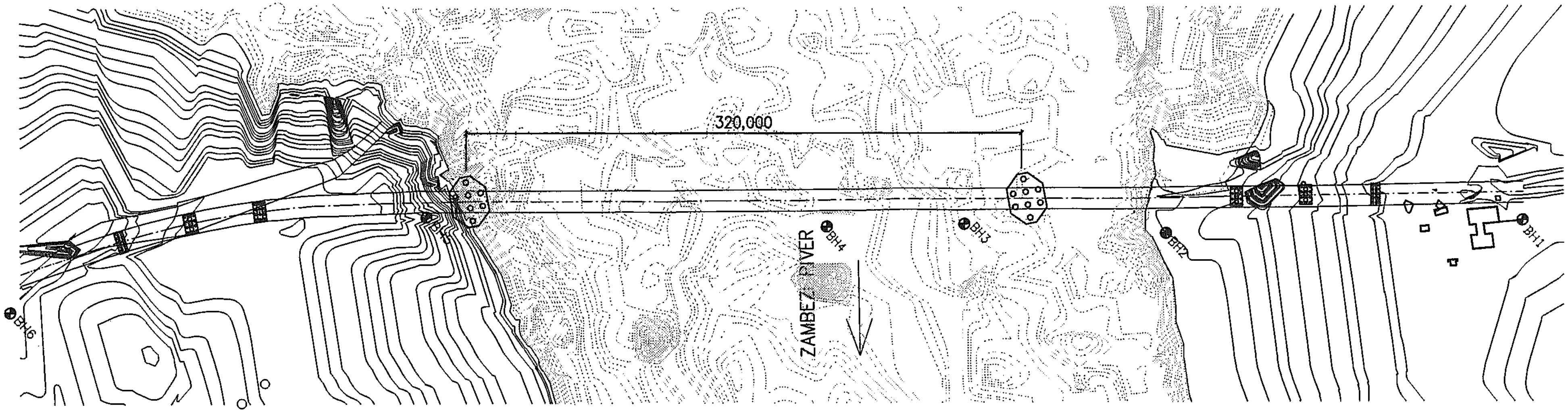
BOTSWANA **PLAN VIEW** **ZAMBIA**

Figure 12.2.10 General View of PC-Exta-dosed (Ls=220m)

PROJECT NAME	IMPLEMENTATION AGENCY	EXECUTING AGENCY	JICA STUDY TEAM	DRAWING TITLE	DWG NO.
THE FEASIBILITY STUDY ON THE PROPOSED KAZUNGULA BRIDGE OVER THE ZAMBEZI RIVER BETWEEN BOTSWANA AND ZAMBIA	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	MINISTRY OF WORKS, TRANSPORT AND COMMUNICATIONS REPUBLIC OF BOTSWANA MINISTRY OF WORKS AND SUPPLY REPUBLIC OF ZAMBIA	NIPPON KOEI CO.,LTD. ORIENTAL CONSULTANTS CO.,LTD	General View of PC-Extra-dosed (Ls=220m)	



PROFILE



BOTSWANA **PLAN VIEW** **ZAMBIA**

Figure 12.2.11 General View of PC Cable-stayed (Ls = 320m)

PROJECT NAME	IMPLEMENTATION AGENCY	EXECUTING AGENCY	JICA STUDY TEAM	DRAWING TITLE	DWG NO.
THE FEASIBILITY STUDY ON THE PROPOSED KAZUNGULA BRIDGE OVER THE ZAMBEZI RIVER BETWEEN BOTSWANA AND ZAMBIA	JICA JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	MINISTRY OF WORKS, TRANSPORT AND COMMUNICATIONS REPUBLIC OF BOTSWANA MINISTRY OF WORKS AND SUPPLY REPUBLIC OF ZAMBIA	NIPPON KOEI CO.,LTD. ORIENTAL CONSULTANTS CO.,LTD	General View of PC-Cable-Stayed (Ls=320m)	

12.2.5 Alternative Study of Foundation Types for the Main Bridge

To select the type of foundation, the following conditions are the basic consideration for each foundation type.

1) The bearing stratum exists at the comparatively shallow soil layer.
2) The resistant rock to support the bridge foundation is basalt with weathered condition of its upper part.
3) The water flow velocities are from 1.0 to 2.0 m/sec at the pier locations during the flooding season.
4) The water depth at the pier location is approximately 8.0 m deep below the water level of 50 years return period river discharge.

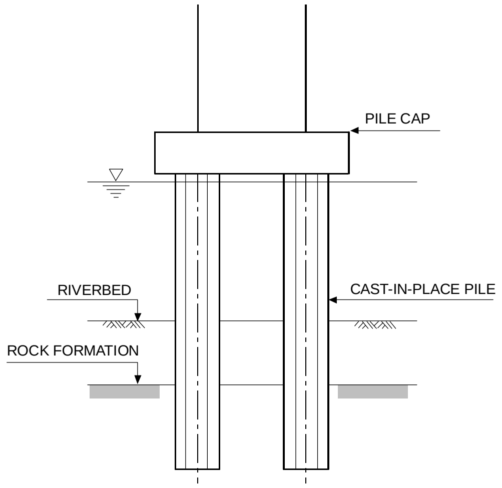
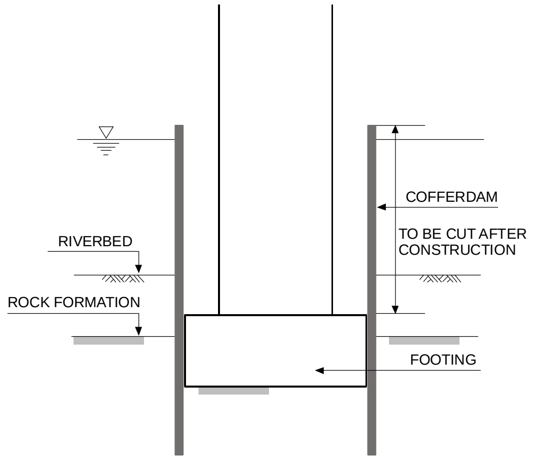
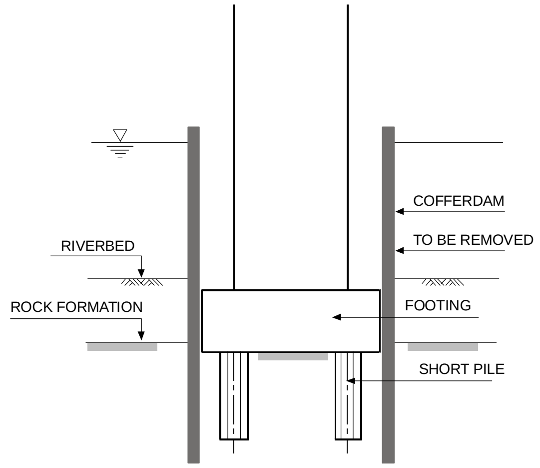
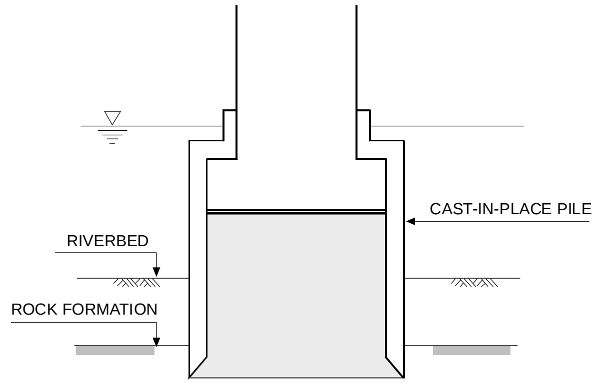
The applicable foundation types are Multi-column Pile, Spread Foundation, Spread Foundation with Shearing Pile and Laying-down Caisson Foundation. From the conditions that the bearing stratum is situated at the comparatively shallow level and resistant basalt rock, the pier's locations are at the deep water (approx. 7.0m) in the Zambezi River which will require the temporary bridge, and need to sustain environmental circumstances.

The factors to be examined for the evaluation of each foundation type are as follows:

1) Structural Features
2) Construction Cost
3) Construction Duration
4) Environmental Aspect

Consequently, Alternative-1: Multi-Column Pile Foundation was recommended mainly from the reasons of cheaper construction cost and shorter construction duration.

Table 12.2.3 Comparison Study on Foundation Type of Main Bridge

Description	Alternative-1: Multi-Column Pile Foundation	Alternative-2: Spared Foundation with Steel Pipe Sheet Pile	Alternative-3: Spread Foundation with Shearing Pile	Alternative-4: Laying Down Caisson Foundation
Schematic Illustration and Construction Method	 - Preparation of Temporary bridge - Drilling by using rotary casing with water jet - Clean the hole drilled - Installation of re-bar cage and pour the concrete - Construction of pile cap and pier shaft	 - Preparation of temporary bridge - Drilling the riverbed by using rotary casing with water jet - Installation and driving of steel pipe sheet pile with grouting cement - Dewatering inside cofferdam - Construction of footing and pier shaft, connect concrete footing with steel pipe sheet pile - Cutting upper part of steel pipe sheet pile	 - Preparation of cofferdam (installation and driving of steel pipe sheet pile) is same as Alternative-2 - Drilling the shear keys at the bottom of the footing and install the re-bar cage and pour the concrete - Dewatering inside cofferdam - Construction of footing and pier shaft - Cutting upper part of steel pipe sheet pile	 - Preparation of foundation bed in the bearing stratum layer - Preparation of precast concrete caisson yard and production of concrete caisson - Draw and install the concrete caisson at the pier location - Fill the caisson inside with gravel and sand and pour the poor mixing concrete - Dewatering and construction of footing and pier shaft
(1) Structure Features	- Since pile cap is constructed above water, the duration of construction period is shorter. - Drilling by rotary casing provides the stable foundation piles in the weathered rock. ○	- Steel pipe sheet pipe with grouting is to be connected with the concrete footing, which maintains the stable bearing condition below and around the concrete footing. ○	- The concrete shear keys below the concrete footing withstand the horizontal sliding force. - Steel pipe sheet piles are cofferdam purpose only. Δ	- Precast concrete pier caisson is massive structure. - Production of concrete pier caisson and foundation bed in the river are prepared simultaneously. Δ
(2) Construction Cost (CostRatio)	1.00 - Preparation of equipment is comparatively simple and working steps are less. ⊙	1.36 - Drilling the holes for steel pipe sheet piles is costly. Δ	1.48 - Drilling the holes for steel pipe sheet piles and construction of concrete shear keys are costly. Δ	1.95 - Preparation of production yards of pier caisson and excavation of the riverbed are costly. ×
(3) Construction Duration per Single Foundation	- About 3.5 months ○	- About 4.5 months ○	- About 6 months Δ	- About 9 months ×
(4) Environmental Impact	- Drilling for the foundation piles produce mud water, but rotary casing is able to minimize its spreading. ○	- Drilling the riverbed and grouting the cement for steel pipe sheet piles would contaminate the river water. Mitigation shall be considered. ×	- Drilling the riverbed and grouting cement for steel pipe sheet piles would contaminate the river water. Mitigation shall be considered. ×	- Due to the excavation of the riverbed for pier caisson foundation, mud water would be spreaded. Water contamination will be less than Alternative-2 & 3. Δ
Total Evaluation	**To be recommended** mainly from cheaper cost and shorter construction duration	**Not recommendable** due to high cost and environmental impact	**Not recommendable** due to high cost and environmental impact problem	**Not recommendable** due to high cost and longer construction duration

Note: ⊙: Excellent ○: Good Δ: Fair ×: Worse

12.3 Alternative Road Alignment and Selection of Road Alignment

12.3.1 Design Conditions

Horizontal alignments are considered based on the following design conditions:

(1) The alignment should not be planned within Zimbabwe. Clearance between the edge of bridge and Botswana-Zimbabwe border should exceed 5 m.
(2) Border facilities in Zambia will be removed.
(3) Ferry facilities in Zambia and Botswana should be removed during the construction. The ferry will not be operated after opening of the bridge.
(4) The proposed alignment is accessed using the existing roads.
(5) Clearance between Center of transmission line and edge of bridge should be kept to a minimum of 15 m according to ZESCO regulations.
(6) The alignment can be planned in the military barracks of Botswana.
(7) Horizontal alignment of the bridge section is planned as a straight line as far as possible, because the bridge can then be planned as a simple structure.

12.3.2 Alternative Road Alignment

Three alternative horizontal alignments were considered in Botswana. Table 12.3.1 outlines each alternative while they are shown on Figure 12.3.1.

Table 12.3.1 Horizontal Alignment Considerations

Items	Alternative 1	Alternative 2	Alternative 3
Summary	-Alignment of bridge section on the river is straight. -Alignment avoids military barracks. -Border facilities are planned in wild park area.	-Alignment of bridge section on the river is straight. -Alignment passes in a section of military barracks. -Border facilities are planned in wild park area.	-Alignment of bridge section on the river is straight. -Alignment passes in area of military barracks. -Development area in wild park area can be reduced because border facilities are planned in wild park area and military barracks area.
Minimum Radius of Horizontal Curve	300 m	300 m	300 m
Horizontal Alignment	-Alignment of bridge section in Botswana side is smaller than Alternative 2 (R=300 m).	-Alignment of bridge section in Botswana side is biggest among alternatives (R=500 m).	-Alignment of bridge section in Botswana side is smaller than Alternatives 2 (R=300 m).
Wild Park Area	-Development area in wild park area is biggest among alternatives.	-Development area in wild park area is smaller than Alternative 1.	-Development area in wild park area is smallest among alternatives.
Border Facilities	-Existing border facilities in Botswana will be used. The facilities, however, will be improved.	-Existing border facilities in Botswana will be used. The facilities, however, will be improved.	-Existing border facilities in Botswana will be improved.
Ferry Facilities during construction	-Improvement is needed.	-Improvement is needed.	-Improvement is needed.
Evaluation	△	○	◎

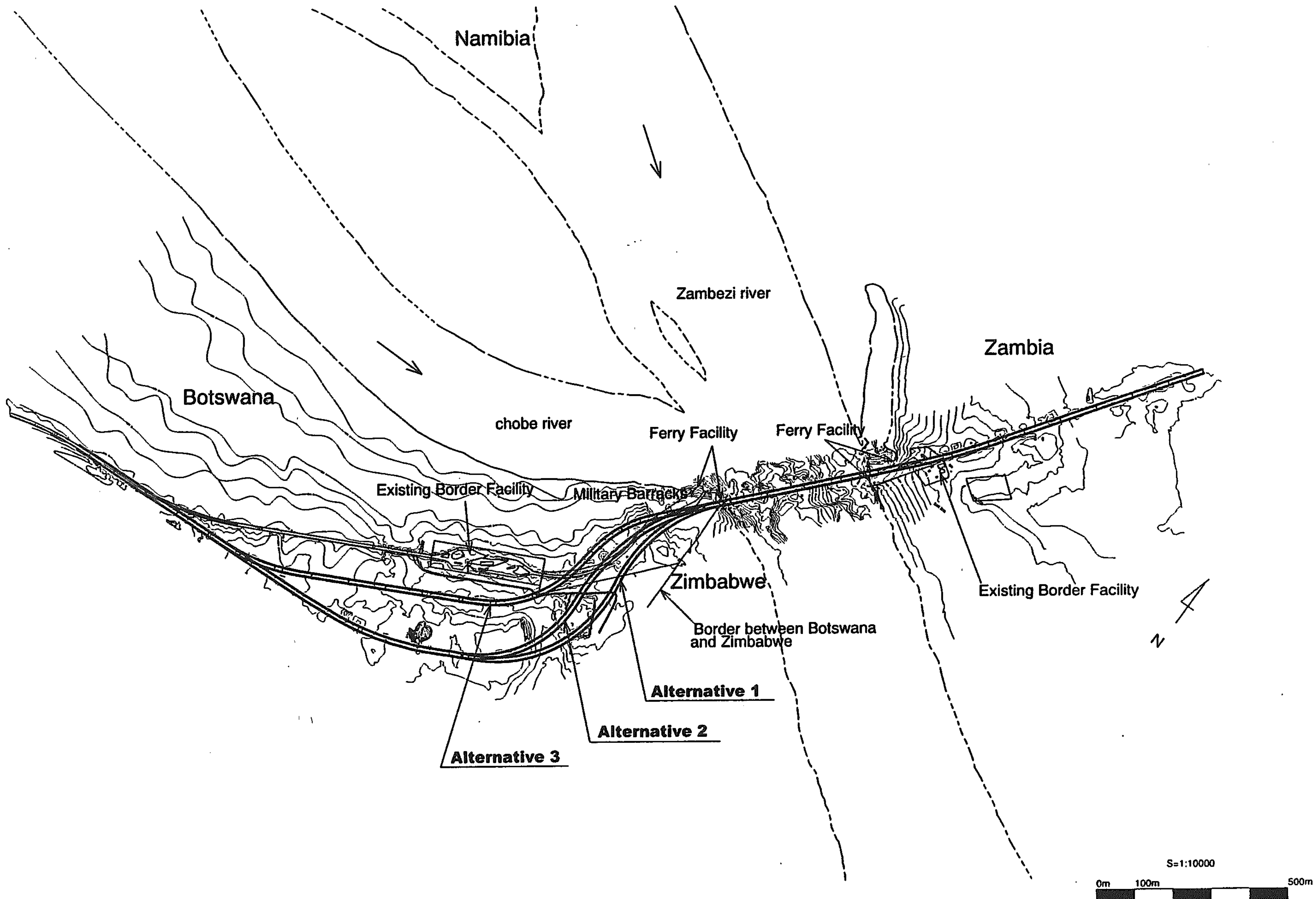


Figure 12.3.1 Alternative Road Alignments

PROJECT NAME	IMPLEMENTATION AGENCY	EXECUTING AGENCY	JICA STUDY TEAM	DRAWING TITLE	DWG NO.
THE FEASIBILITY STUDY ON THE PROPOSED KAZUNGULA BRIDGE OVER THE ZAMBEZI RIVER BETWEEN BOTSWANA AND ZAMBIA	JICA JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	MINISTRY OF WORKS, TRANSPORT AND COMMUNICATIONS REPUBLIC OF BOTSWANA MINISTRY OF WORKS AND SUPPLY REPUBLIC OF ZAMBIA	NIPPON KOEI CO.,LTD. ORIENTAL CONSULTANTS CO.,LTD		

12.3.3 Selection of Road Alignment

As a result of an evaluation of Table 12.3.1, the Alternative 3 horizontal alignment is proposed. The characteristics of this alignment are as follows:

(1) Minimum radius of curve is 300 m.

(2) New alignment is approx. 3 km.

Botswana side: Approximately 2 km

Zambia side: Approximately 1 km

(3) The crossing length on the river in the dry season is approximately 400 m.

(4) Alignment passes through a section of the military barracks in Botswana.

(5) Development area in wild park area is smallest because border facilities are planned in military barracks. Therefore, military barracks must be removed.

(6) Ferry facilities must be removed.

12.4 Alternative Ferry Facilities in Accordance with the Location of Project Route

Based on the selected route for the bridge and road (Routes A, B, or C), problems will arise with ferry operation during construction. For that reason, countermeasures are summarized below in Table 12.4.1 with alternative plans for each route.

Table 12.4.1 Alternative Plans

Route	Problem	Required Facilities
A Route	None	-Reconstruction of onshore ramp -Reconstruction of parking lot
B Route	- Change of ferry route - Change of basin	-Reconstruction of onshore ramp -Reconstruction of parking lot -Construction of new basin
C Route	- Replacement of onshore ramp - Replacement of parking lot	-Construction of new onshore ramp -Construction of new parking lot -Dredging work in front of new onshore ramp

Regarding each route, the detailed problems are outlined below.

(1) Route-A

The problems associated with this route (shown in Figure 12.4.1) are not significant, reflecting the distance between it and the existing ferry facility and ferry route. However, onshore ramps on the Zambian and Botswana sides should be reconstructed. The parking lot on the Zambian side should also be improved and expanded as it is insufficient in area and in poor condition for unloading of vehicles.

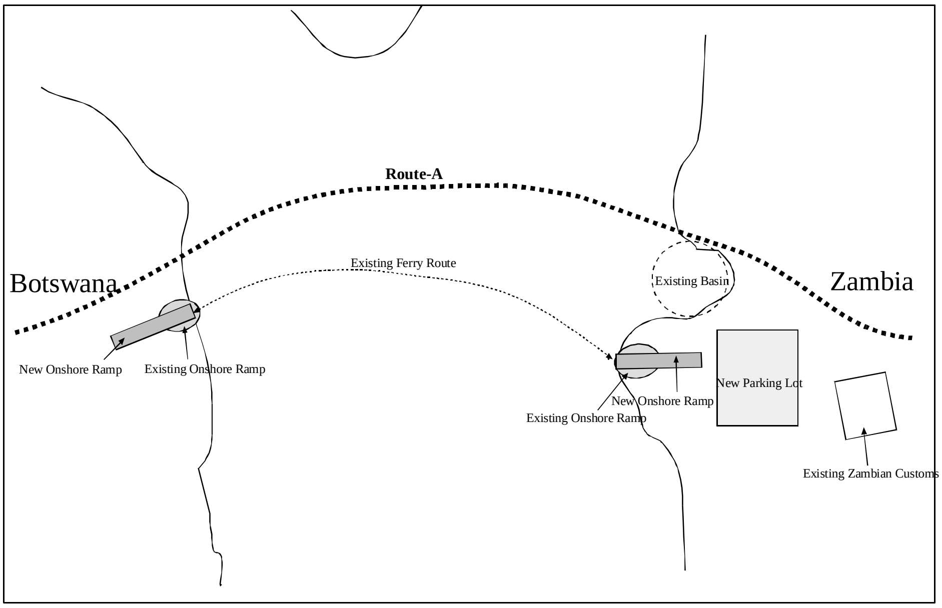


Figure 12.4.1 Relocation and Construction of Ferry Facilities (Route-A)

(2) Route-B

It is not necessary to replace the existing ferry facilities as this route is located some distance away, as shown in Figure 12.4.2. However, the basin where the pontoons are currently anchored when not operational will be affected. As no other suitable anchoring areas are available in the vicinity of Kazungula, this will create significant difficulties, particularly during the high flow season.

Normally, when two pontoons operate at the same time, one passes on the upstream side of the main ferry route. However, this coincides with the construction site for the bridge. Hence, the route for ferry operation should be changed to the downstream side to prevent interference with construction work and possible accidents.

Although it is not necessary to replace the onshore ramps, it is recommended that this be undertaken to improve the overall ferry operation. In addition, the parking lot should be improved and expanded to reduce the cycle time for vehicles.

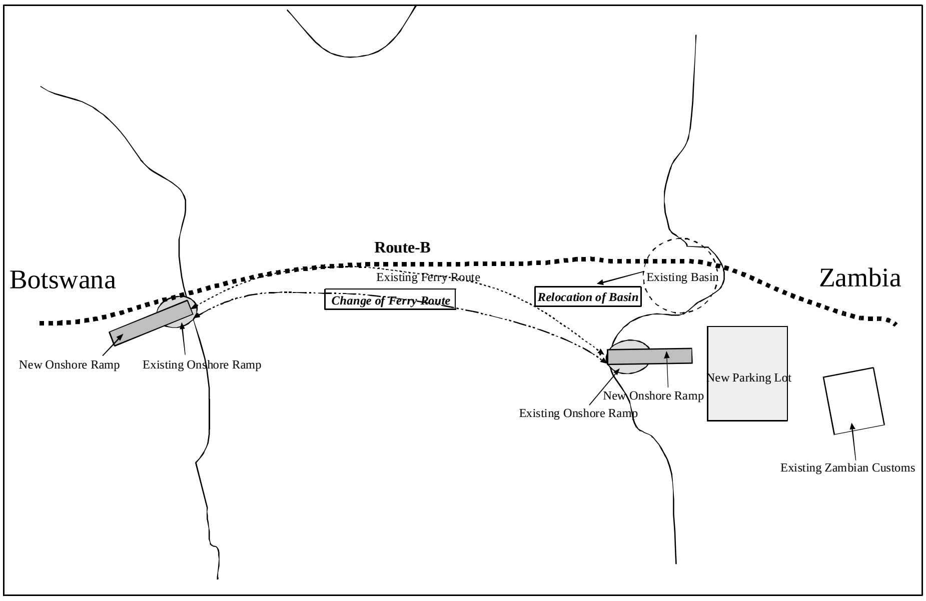


Figure 12.4.2 Relocation and Construction of Ferry Facilities (Route-B)

(3) Route-C

For this route, shown on Figure 12.4.3, relocation of existing ferry facilities will be necessary. It will also be necessary to construct new onshore ramps on both the Zambian and Botswana sides and a parking lot in Zambia to improve ferry operation and transfers during construction of the bridge and road. In addition, to ensure adequate draft for the ferry during full loading, dredging will be required in the river channel adjacent to the onshore ramps on both sides to facilitate safe ferry operation. The location of ferry facilities should be moved upstream of the construction site for the bridge in order to avoid accidents between the pontoon and bridge during construction.

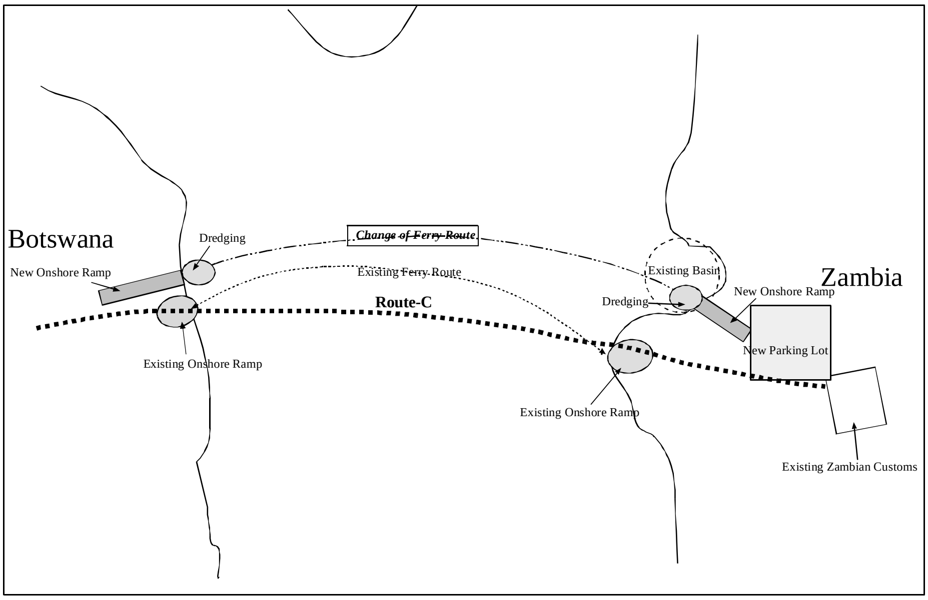


Figure 12.4.3 Relocation and Construction of Ferry Facilities (Route-C)