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The Feasibility Study on the Kafue Road Bridge Reconstruction Project in the Republic of Zambia

Summary Report

October, 1990

Japan International Cooperation Agency

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Contents

SUMMARY

The Kafue Road Bridge is located 56 km to the south of the capital city, Lusaka, on the main trunk road running from the north of the country to the south through to southern African countries. The region through which the road passes is the most fertile agricultural and consumptive area. Consequently, the road is one of the most important aspects for the development of the Republic of Zambia.

The Superstructure of the existing Kafue Road Bridge was constructed across the Thames River in beginning of 1940's. The bridge was relocated to Kafue River in 1949 and has subsequently been raised and improved in 1968.

The bridge has been in use for some 50 years since its original construction and suffered from heavy traffic conditions requiring constant maintenance and surveillance. Besides, heavy vehicles have been obliged to give way for face-to-face traffic due to the insufficient width of traffic lane on the Bridge.

In Zambia's successive plans, the development of transport and communications has been one of the highest priorities in view of the fact that Zambia is a land-locked country.

In order to promote the social and economic development of the vital sectors of economy such as agriculture, mining, manufacturing and trade, it is necessary to improve existing infrastructure and facilities, and to ensure the road transport for foreign trade.

Due to these circumstances, the government of Zambia made a request to the government of Japan to pursue a feasibility study of the bridge's reconstruction.

The Japan International Cooperation Agency, the official agency responsible for the implementation of technical cooperation programme of the Government of Japan, and the Ministry of Power, Transport and Communications, the Government of Zambia, agreed on the Scope of Work for the Feasibility Study on the Kafue Road Bridge Reconstruction Project on 10th March, 1989.

The Study commenced in November 1989 and completed in October 1990.

The Study comprises two phases. The major activities of each phase include the followings;

Phase I:

1) Preparatory Works
2) Collection and analyses of data and information
3) Inspection of the existing bridge
4) Preliminary surveys
5) Traffic survey and forecast of future traffic demand
6) Bridge alternative study and selection of bridge type
7) Detailed surveys

Phase II:

1) Preliminary engineering design
2) Socio-economic evaluation

The Study concluded the Kafue Road Bridge was on delicate balancing condition and might suffer possible destruction by becoming unstable due to unidentified factors. Although to predict collapse is beyond the binds of structural analysis and most likely impossible, it is required in above context to urgently replace the Bridge, considering importance of the Bridge and social consequence by its possible destruction.

The reconstruction programme of the new Kafue Road Bridge is as outlined below:

1. Features of the Bridge

(1) Bridge Length 162.0 m

(2) Span Length 38.0 m + 43.0 + 43.0 m + 38.0 m

(3) Cross Section Carriageway; 3.65 m × 2 = 7.30 m
Footpath ; 1.00 m × 2

(4) Type of Superstructure
4-continuous span plate girder

(5) Type of Substructure
Pier ; Pile Bent
Abutment; Reversed T type (A1)
Caisson Type (A2)

(6) Type of Foundation
Pier ; Pile Foundation
Abutment ; Spread Foundation

(7) Length of Approach Roads
750 m

2. Implementation Programme

(1) Construction Cost
Approx. 2,000 million yen

(2) Construction Period

Approx. 24 months

The reconstruction of the Kafue Road Bridge is expected to contribute to industrial development of the Republic of Zambia, as the new bridge ensures improvement of safety and copes with the increasing traffic volume.

1 INTRODUCTION

1.1 BACKGROUND

In Zambia's successive plans, the development of transport and communications has been one of the highest priorities in view of the fact that Zambia is a land-locked country.

In order to promote the social and economic development of the vital sectors of economy such as agriculture, mining, manufacturing and trade, it is necessary to improve existing infrastructure and facilities, and to ensure the road traposport for foreign trade.

The Kafue Road Bridge is located 56 km to the south of the capital city, Lusaka, on the main trunk road running from the north of the country to the south through to southern African countries. The region through which the road passes is the most fertile agricultural and consumptive area. Consequently, the road is one of the most important aspects for the development of the Republic of Zambia.

The Superstructure of the existing Kafue Road Bridge was constructed across the Thames River in beginning of 1940's. The bridge was relocated to Kafue River in 1949 and has subsequently been raised and improved in 1968.

As for the bridge conditions, the bridge has been in use for some 50 years since its original construction and suffered from heavy traffic conditions requiring constant maintenance and surveillance. Besides, heavy vehicles have been obliged to give way for face-to-face traffic due to the insufficient width of traffic lane on the Bridge.

1.2 OBJECTIVES

The objective of the Study is to carry out the feasibility study for reconstruction of Kafue Road Bridge including its approaches and connection Roads.

The Study conclusively proposed most suitable bridge plan to be replaced with the existing bridge, its span lengths, most suitable alignment and implementation programme.

1.3 STUDY FLOW AND SCHEDULE

The Study comprises two phases. The major activities of each phase include the followings;

Phase I :

1) Preparatory Works
2) Collection and analyses of data and information
3) Inspection of the existing bridge
4) Preliminary surveys
5) Traffic survey and forecast of future traffic demand
6) Bridge alternative study and selection of bridge type
7) Detailed surveys

Phase II :

1) Preliminary engineering design
2) Socio-economic evaluation

The flow chart of the study is shown in Table 1.

The study commenced in November 1989 and was completed in October 1990.

2 ROADS AND TRAFFIC IN ZAMBIA

2.1 ROADS SYSTEM

1) Roads Classification

In Zambia, roads are classified in accordance with Highway Design Standards by Road Department enacted in 1965 and revised in 1971.

Standard Specifications for Bridge and Culverts enacted in 1968 has been in use for stipulations of Bridges.

2) Roads Length

Length of roads pertaining to the classification is as follows:

(1987)

Classification		Class I			Class II	Class III	Others
		A	B	C			
Future ADT		1,500 ~5,000	500 ~1,500	150 ~500	50 ~150	20 ~50	
Carriageway Width (m)		7.3	6.7	6.1	Min. 6.1	Min. 5.5	
Design speed(km/h)		100	100	100	80 ~100	60 ~80	
Road Length (km)	Road Dept.	6,236.9			2,277.2	6,201.0	6,663.6
	Province	80.0			0	0	15,900.1
	Total	6,316.9			2,277.2	6,201.0	22,563.7

2.2 ROAD NETWORK

Road network in Zambia is summarized as follows:

(1987)

	Road Network	Length(km)
Inter-Territorial Main Road ("T")	"T" roads are to link major cities in Zambia and neighboring countries and are composed of following 5-routes" T1 ① Livingstone - Zimbabwe ② Muwunba - Kafue T2 ① Chirundu - Kafue - Lusaka ② Lusaka - Kaburimwosi ③ Kaburimwosi - Twunduma T3 Kaburimwosi - Ndola - Chingola T4 Lusaka - Chipata T5 Chingola - Mwunirunga	3,118.6
Territorial Main Road ("M")	1st class road to form domestic road network with "T" roads	4,047.8
District Roads ("RD")	2nd class road to connect T and M roads with regional cities	23,882.0
Rural Roads ("R")	Roads to form rural network	5,714.3

2.3 RESULTS OF TRAFFIC COUNTING SURVEY

(1) Total Volume

At Kafue Road Bridge, the Study Team carried out the 24 hours Traffic Counting Survey on 11th and 14th Dec. 1989. The results of traffic counting is shown as follows.

The total traffic volume was 1,116 vehicles on 11th Dec. and 1,128 vechicles on 14th Dec. The number of vans was above twice of the passenger cars and it shares 40% of total vehicles. 2 axles truck accounted for 16% of total vehicles and is equivalent in volume to trailers. Passenger cars and vans shared 60% and trucks and trailers shared 35% of total vehicles. These percentages show the rate of heavy weight vehicles is enormously high.

(2) Daily Variation

As a whole, two peak hours such as 10:00-11:00 and 3:00-4:00pm are formed. The peak ratios in the morning and evening peak hours accounts for 7.6% and 8.4% of the total traffic volume, respectively.

The result shows peak hours vary depending upon type of vehicles. As a matter of fact, peak period of passenger car, truck and trailer are 4:00-5:00pm, 5:00-6:00pm and 10:00-11:00am, respectively.

Volume of truck and trailer found stable throughout a whole day. Hourly truck volume and peak-hour truck volume are not much different. Volume of trailer heavily fluctuates and is repeatedly up to the midnight. A pattern in daily variation of passenger car is typical and has two (2) peak hours as explained previously.

(3) Vehicle Type Structure

The structure of vehicle types at peak-hour is shown in the following table.

(Unit: %)

Time	P/Car	Truck	Trailer	Bus.	Total
10:00-11:00	63.5	13.0	23.5	0.0	100.0
15:00-16:00	67.0	16.0	16.0	1.0	100.0
16:00-17:00	69.9	17.2	12.9	0.0	100.0
17:00-18:00	67.1	24.4	8.5	0.0	100.0
Total	62.2	18.5	17.8	1.5	100.0

Source : Study Team Survey on 11th Dec. 1989

The percentage of passenger cars shows 62.2% in the average daily traffic volume (total volume).

(4) Axial Load Survey

These check were performed on January 29, 1990 at the southern approach to this "Kafue Bridge", at a point on the northern side of a local traffic check point. The target vehicles for these checks were trucks (that is, lorries) laden with cargo. At the same time, an O-D survey was also carried out. All the vehicles checked were running from south to north (in the direction of Lusaka). Almost all the vehicles were found to be overloaded, to exceed their specified loading capacities by 30 to 50 %. Similar findings were seen in the recordings of weighbridges at various other points in the country. This was something to require consideration in designing the bridge floor structures everywhere in this African country.

3 INVESTIGATION ON THE EXISTING BRIDGE

In making this investigation, whatever existing drawings of the bridge were studied for reference in identifying the present conditions of the bridge through on-the-spot measurements and gaugings as well as visual inspections. But as far as the existing designing literature concerning the bridge were concerned, all what were found to be remaining were only those drawings of the bridge at the time when it was last raised in height. Worse still, there were no recorded measurements of the key parts of the upper structure of the bridge. Besides, as for the substructure, there did remain some drawings for the heightened portions of the bridge, but much was left unknown as to the foundations of the bridge, of which only some reproduced copies of drawings used way back at the time of the construction of the bridge were available. Thus, just how the bridge's foundations were embedded in practice was unknown.

3.1 SUBSTRUCTURE

1) Piers:

Part of the piers, being underwater, could not be directly checked. But visual observations from above the water and a measurement of the strength of the piers by means of a concrete hammer resulted in a judgement that the piers were still sound, in general.

2) Abutment:

The abutments that were made of concrete were likewise determined as generally still sound. However, judging from the conditions of the expansion joints of the from the conditions of the expansion joints of the bridge's superstructure, it was feared that the abutments have shifted toward the middle of the river or slanted toward that line. The earth retaining walls on both banks were found to have also shifted to create wide gaps from the adjacent abutments. Whether such dislocations are on-going phenomena or not was hard to confirm during the limited period of the surveys.

3) Foundations of the Piers:

To sum up the findings from our river water depth measurements and also our geological investigation concerned, it was inevitable to decide that the river beds around the feet of all the bridge piers had been scoured by the stream so deeply that each pier's foot now has hardly any depth of embedment in the river bottom. According to the still remaining drawings, each bridge pier is a cylinder of 6 feet in diameter. Out calculation of the stability of each pier on the basis of that cylinder structure has shown that theoretically, the pier should collapse at a lateral seismic coefficient of k=0.03. That corresponds to about 6 tons of load in a horizontal force to come down from the superstructure. (See Fig. -1) The bridge, as it now stands, looks as if it were in a state of pin connection. Thus, as a whole, the bridge now seems to be in quite a stable condition. Nonetheless, it is beyond the bounds of any stability judgement in terms of structural dynamics to discuss the danger of collapsing destruction of the bridge as it now stands. It is, therefore, impossible to decide whether the present condition of the bridge is bound to lead to such a destruction to occur any time in future. For all that, the danger of a chance destruction by some external stimulus cannot be dismissed.

4) Abutment Foundations:

As referred to above, the abutments were found to have been deformed. Thus, their stability in the axial direction could hardly be called high enough. Fortunately, Zambia has hardly experienced a strong earthquake to pose any seismic problem with the abutment stability.

3.2 SUPERSTRUCTURE

The principal structural parts like trusses and floor systems were checked for their sizes by actual measurings, and for their material deterioration by visual inspection. As the result, it was discovered that crashes of some passing motor vehicles or those of the cargo carried by such vehicles damaged some verticals or diagonals of one of the spans on the southern side of the bridge. But, otherwise, the bridge was found to be generally in a good state of maintenance with few points of rusting corrosion. (See Fig. 3, 4, 5, 6)

But, on the other hand, a series of three trusses, due to deformation of their abutments, were found to be in a state of fused connection of the originally separate three spans. Thus, the bridge's superstructural parts may still have enough resistance to the normal kind of load with a maximum stress of 1,000 kg/cm^2. But considering a secondary stress to occur due to a temperature change or some other factors, that calculated stress should be considered excessive.

As for the width of the bridge's deck surface, it was found to be 6.1 meters. Thus, it was dangerous for two large motor vehicles running in opposite directions to pass each other on the bridge. The width of the bridge was doubtless insufficient as a part of the trunk highway it constitutes in the southern part of Zambia. That width insufficiency will be more acutely realized when compared with the width of the Kafue-Chilundu highway south of the bridge that has been reconstructed, and also the width of the Kafue-Lusaka highway north of the bridge, on which a reconstruction project is scheduled.

4 SITE INVESTIGATION

4.1 TOPOGRAPHICAL SURVEYS

For the purpose of obtaining the necessary reference data for conceptional designing of alternative plans for the present project, the following kinds of topographical surveys were undertaken:

1) Water Depth Checks:

The river's depth was checked across the stream at 6 points: the location of the present bridge: one point 50 meters upstream of the bridge: and four points downstream of it --- respectively 15, 50, 100, and 150 meters away. As the result, it was found that the nearer to the bridge, the deeper were the river bottoms, to show what effect the construction of the bridge has had on the river depth.

2) Scouring Checks:

A close survey was held in the vicinity of each bridge pier so as to find out a possible scouring phenomenon (around each pier foot) on the river bed. This survey itself showed that, to all appearance, there was no scouring phenomenon. Nonetheless, when the whole results of this series of geological checks, as will be given later here, were coordianted, it was clearly confirmed that the original river bottoms around or near the piers of the existing bridge were first scoured, that is, washed away down to the basic rock bottoms, and therefore, mud and sand particles set afloat after a Kafue Gorge Dam construction project have come to be deposited on the scoured river bottoms.

Thus, the depths of the present river bottoms (involved in our surveys) happened to coincide roughly with those determined in an equivalent topographical survey of 1952. This meant that the river bottoms around or near the bridge piers are now covered with soft, fragile layers of mud about 2 to 4 meters deep.

3) Detailed Topographic Survey:

The following kinds of topographic surveying were carried out along a newly-set route for building the proposed new bridge and also along the conventional route of construction of the existing bridge:

1) A central line traversing survey:

to determine the benchmark of a given selected route (the route: about 1.6 km in distance: to be shown in a 1/200th scale: to include the river depth survey results)

2) A cross section survey:

to determine the cross section, over a 60-m width, of a given selected route (a 20-m interval + a special cross section)
About 100 cross sections (inside the river, only cross sections of piers and girders)

3) A horizontal survey:

to produce pictures of the bridge deck over the girders in a 1/200th scale (one picture is to be produced at two spots, each about 25 m x 20 m)

4.2 A DETAILED GEOLOGICAL SURVEYS

A detailed kind of boring checks was held at each point chosen as close as possible to the piers and girders of the designated main bridge. The results of this kind of survey, along with the results of the preliminary survey of the same kind, are given in Fig. 7 and 8.

As for banking sections of this whole project, a dynamic penetration cone test was performed.

4.3 HYDROGRAPHIC SURVEY

The reference data resulting from the river water depth checks were analyzed and new reference data necessary for the construction of a new bridge were prepared on the basis of that analysis. The river flow around the existing bridge was being maintained below a certain water level by a technological arrangement to properly regulate the volume of water to be released at the Iteshi-Teshi Dam upstream of the bridge and at the Kafue Gorge Dam downstream. The water flow near the bridge is predominantly controlled by the water discharges at the Kafue Gorge Dam. Normally, those water releases average 650 m^3/sec or so, and the water flow at the bridge piers will then range between 0.2 m/sec and 0.4 m/sec. The water flow and the water level forecasts used in the official plan for the same dam stand as follows:

Return Period (years)	Flow (m^2/sec)	Water Level at Kasaka (m)
	2040	

100	-	2120		
		2270		
		2550		
		2750	-	976.3
		2830		
		3060	-	977.2
		3120		
1,000	-	3340	-	977.8
		3540		
		3620	-	978.4
		3960	-	979.0
10,000	-	4250	-	979.6

If the expectation value in terms of 100 years is to be applied to the designing of the proposed new bridge, the volume of the water flow could come to 2,120 m^3/sec and the flow speed to 2.5 m/sec. Such a flow speed is fast enough to require attention to the scouring of the river bottoms. Seen from such standpoint, a wider width of the river is desirable.

Meanwhile, the water level is to be so regulated by controlling the water releases at the dam as it will not exceed 976.6 m at the Kasaka water level observatory (located about 5 km upstream from the present bridge.)

Considering this arrangement, the clearance above the water surface of the girders of the proposed new bridge may be set only at no less than that for the existing bridge without any more margin.

5 BRIDGE ALTERNATIVES STUDY

5.1 INVESTIGATION OF DESIGN CRITERIA

1) The width of the new bridge and that of the road approaches to it were fixed as shown in Fig. 9 after a consultation with the Roads Department of the Zambian ministry as referred to above, having been harmonized with Zambia's present road-designing standards and similar projects.

2) DESIGN SPECIFICATION

The design specification to apply to the proposed new bridge will be patterned after Standard Specification for Highway Bridge by Japan Road Association. However, special separate provisions will be made as to the design live load; wind load; seismic load, and (the effects of) temperature changes. For whatever accompanying facilities of public use character, some entry space will be prepared in case their entries may become necessary in future.

5.2 ALTERNATIVES STUDY

As alternative bridge plans, 12 new main bridge ideas and one approach idea were drafted, and, five were chosen out of the entire 13 plans for their relatively higher feasibilities.

1) Comparison between a Concrete Bridge and a Steel Bridge:

For the present project, a steel bridge was preferred for reasons as given below:

- To build a concrete structure as the proposed new bridge, the cost will be higher than building a steel structure because, for ensuring a good quality, waterproof concrete-building frameworks and strong stagings-supporting engineering jobs will be needed to require corresponding expenses.

- Prestressed concrete structure would require highly skilled labour and more attention to quality control and supervision throughout site works as compared to steel structures. On the other hand, steel structure are prefabricated at the shop and can be erected by a few skilled technician and local labour under supervision of expatriate engineers.

- Furthermore, a long span prestressed concrete bridge would require concrete with high quality and high strength of more than 350 kg/cm^2. To fulfill these requirements, good quality sand and gravel and good cement quality would have to be ensured.

- To build such a concrete structure will require a longer time --- by about 4 months --- than building an equivalent-scale steel structure. In order to ensure a good quality of the asphalt pavement over the new bridge as well as over the approaches to it, it will be desirable to complete that pavement job while the local highway reconstruction project is still in progress. To attain such an aim, it will be necessary to carefully harmonize the new bridge-building project with that highway reconstruction project of USAID. For such harmony, the new project had better be completed in the shortest practicable period.

- In the cost of maintenance, the difference between a concrete bridge and a steel bridge will roughly correspond to the cost of repainting the steel bridge for rusting prevention. Zambia is a land-locked country and in a favorable condition for prevention of steel rusting. Each repainting of such a bridge will be required only once in every 10 years. The impact of the maintenance cost (in the case of the steel structure) may be figured out by converting the future maintenance costs into the current values, and adding that converted value to the cost of procuring the steel structure, and then comparing the result with the cost of procuring the concrete structure. The impact in the case of the present project will be about K 0.3m, a very slight one.

2) Five ideas (plans) were chosen for their relative feasibilities after overall evaluations of all candidate ideas (plans) for their economy, workability, reliability, easiness of maintenance and administration, and other factors. (See Table-2)

3) A further study on the five (5) alternatives as selected was made. The plan was thus optimized and a 4-span-continuous plate girder type of bridge (40m+43m+43m+40m) came to be chosen. (See Table - 3)

5.3 DEFINING OF THE DESIGNING CONDITIONS

This was done by reviewing the designing conditions and setting more detailed designing conditions in different terms including loads, materials, etc. The resulting design specification differed from Japan's common design specification for bridge construction in that it included the following conditions as capacities to meet circumstantial changes where there are no such provisions in Japanese statements of the kind:

a. Temperature changes: 0 to 45°C

b. Seismic coefficient: K_h=0.10

c. Design wind velocity: V_{100}=20m/sec

d. Debris load: (normal time) P_{hc}=3.612 t/pier

(anomalous time) P_{hc}=22.575 t/pier

e. Wheel load: 8.2 t

5.4 DEFINING OF THE BRIDGE IN OUTLINE

1) Review of the Span Length:

The best-fit plan chosen in 5.2.3), that is, 4 spans of 40 + 43 + 43 + 40 m in span length, was studied in greater detail. Thus, three alternative plans were comparatively studied for the optimum span length ----- a 33.6 m plan, representing the maximum length of a span that can be assembled on the ground beside the river; a 38 m plan, representing the minimum span length between each foot of the abutment and the first pier; and a 43 m plan representing the same length as the central span of the bridge. After comparing the three plans in terms of economy, workability, and effects on the river, the 38 m plan was chosen as the optimum.

2) Study on the Pier Pile Diameter:

Three plans were compared in overall terms ----- a ϕ800 × 22 (in 2 rows of 10 piles) plan; a ϕ1000 × 22 (one row of 5 piles) plan; and a ϕ1200 × 22 (one row of 5 piles) plan. Finally, a ϕ1000×22 (one row of 5 piles) plan was picked for its decided higher economy and workability.

3) Preliminary Designing:

Preliminary designs were produced as to the superstructure, substructure, and foundation and other phases of the proposed bridge to find out the best suitability as bridge parts.

The principal cross sections as the basic structure are given in Fig. 9.

5.5 PRELIMINARY ENGINEERING DESIGN

For the highway approach to each end of the proposed new bridge, a design in outline has been prepared as to the necessary soil banking, road bed building, pavement and drainage piping. A key cross section of each approach is shown in Fig. 9.

6 IMPLEMENTATION PROGRAM

6.1 CONSTRUCTION COST

A coordinated listed of the key materials in quantity is shown on Table 4~6. The aggregate cost of construction was worked out as approx. 13.2 million US$.

6.2 CONSTRUCTION IMPLEMENTATION PROGRAM

This program discusses and suggests the methods and processes of execution of the whole project.

a) The existing bridge removal: by a bent pile method

b) The new bridge construction: by a bent pile method

c) A temporay bridge pile-driving: by a water jet and vibro method

d) The new bridge pier driving: by a pre-boring and vibro method

Indicentally, the time to be required for completion of the entire project was figured at approximately 24 months (2 years).

6.3 CONSTRUCTION CONDITION

1) Construction Materials:

Except for cement, sand, and gravel, almost all other necessary materials are to be imported. As a rule, Zambia embargoes the import of cement. But, in reality, its domestic cement production is falling short of its mounting demand for the item. As things so stand, there will be a need for importing cement as an inevitable exception unless there is a never-failing guaranty of local supply of the needed cement.

2) Construction Machinery:

Except for the transportation machinery of common types, the necessary machinery are to be also imported.

3) Workers:

No skilled workers capable of helping in bridge construction engineering jobs are locally available.

4) Others:

Nearby facilities to be relocated according to the construction of a new bridge would include telephone lines and electric power transmission cable lines. If a new bridge is to be built along a route on the south side of the existing bridge, at least the telephone lines will need relocation. If the new bridge is to be built on the same route as the existing one, there will be no accompanying facility to relocate.

As for some new facilities to be built as accompaniments to the new bridge, there is none, as so far visualized.

7 SOCIO-ECONOMIC ASPECT OF PROJECT

7.1 SITUATION OF KAFUE ROAD BRIDGE IN NATIONAL ROAD NETWORK

The road passing through the Kafue Road Bridge is a trunk line which joins Lusaka City and Southern Province in Zambia, and furthermore outside southern African countries (i.e. Zimbabwe, Botswana, and Mozambique).

7.2 ROLE OF KAFUE ROAD BRIDGE IN EXTERNAL TRADE

According to the statistics of trend of transport volume of export and import by route/mode of Zambia during 1986 - 1988 compiled by Central Statistical Office, Zimbabwe and Botswana Border Routes in road mode which are related to the Kafue Road Bridge have share portions of about 10% in all modes, and about 15% in modes except pipe line for three year's average in export and import.

This indicates that the Kafue Road Bridge corridor plays a respectable role for transport in the external trade.

7.3 PROJECT ECONOMIC ANALYSIS

1) Elimination of Risk of Bridge Unserviceability

In this economic analysis, bridge unserviceability is assumed with some probability.

It is assumed that in the case of bridge unserviceability, some portion of vehicle traffic which pass through the Kafue Road Bridge in a normal condition will be diverted to alternative routes, i.e. detour routes.

Although detour routes have some requirements to be considered counterplans, it is assumed that detour routes are available and requirements are not treated as a cost factor, in this economic analysis.

As a detour route for the Kafue Road Bridge, Itezhi Tezhi Route and Chiawa Pontoon Route are assumed.

Increase of vehicle operating cost by diversion to detour routes is regarded as an economic benefit.

That is, an effect of eliminating a risk of bridge unserviceability is embodied as a saving of vehicle operating cost.

2) EIRR

Economic Internal Rate of Return (EIRR) which is an indicator of economic analysis is estimated for the assumed detour routes as follows:

- Case of Itezhi Tezhi Route: 80.1%
- Case of Chiawa Pontoon Route: 51.9%

These calculation results indicate that an impact of unserviceability of the Kafue Road Bridge is considerably heavy.

It can be recommended that in order to eliminate a risk of bridge unserviceability, a need of reconstruction of bridge is fairly high.

8 CONCLUSION

Some eighty (80) years has passed since the Kafue Road Bridge was initially constructed. Generally speaking, durable years of the bridge is exceeded. Irrespective of the fact, each structural member of the superstructure is fairly sound, though a part of members is destroyed and lost, and these have to be remedied.The width of the present Kafue Road Bridge is 6.1m. And allowance between edges of carriageway and structural members of the bridge is narrow. Consequently, to pass each other on the bridge is unable for large-size vehicles and therefore, the present traffic condition is undesirable from a standpoint of traffic safety. On this particular road, a ratio of large-size vehicles is high and it is assumed that this trend will continuously maintained. From this point of view, too, the width seems insufficient.

The river bed of both up and downstream of the bridge is broadly scoured after construction. And this results in scarce footing of pier foundations into the bearing stratum and difficulty of piers' self-standing. Thus, piers are assumed to be in a condition that they may be collapsed at a sudden.

Reinforcing these piers is troublesome, since the water depth is 8-10 m and the river bed is composed of mud on which no bearing is expected and hard rock exposed underneath the mud. The reinforcement is anticipated to be more expensive than the replacement.

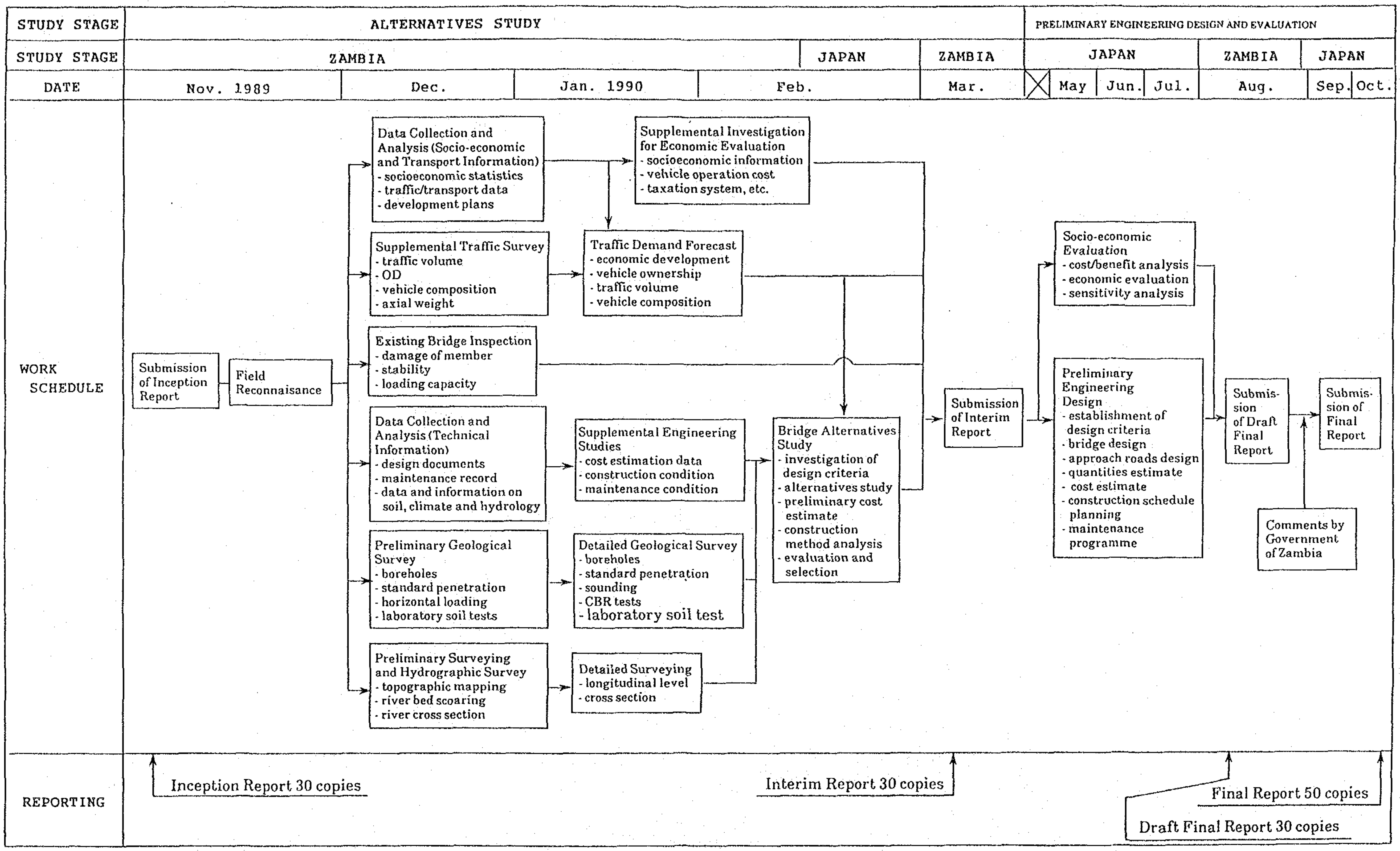
The southern road of the bridge has been rehabilitated, and the northern road is to be rehabilitated up until Lusaka. Therefore, the bridge will be a bottle-neck of the traffic, unless reconstructed.

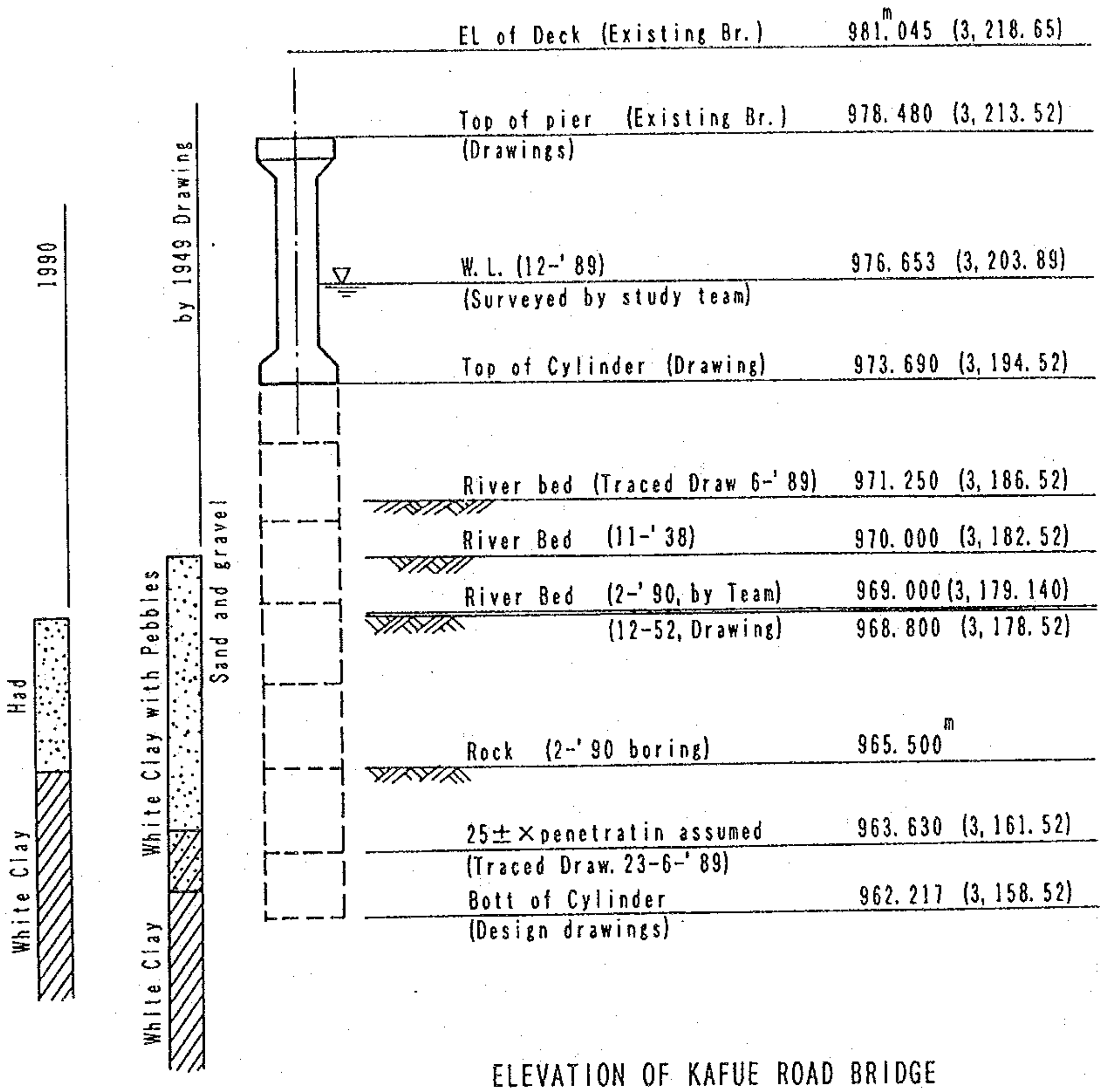
In such a case as reconstruction of the Kafue Road Bridge that is a sole bridge on a link of international trunk roads in the Southern region, consequence on society, economy and defense as well as impact to direct users is extremely large. In addition, it is complicated and troublesome to indicate the consequence by an amount of money. Needless to say, a direct affect due to the Kafue Road Bridge being unserviceable is awfully great, since a potential detour route is not fixed and is far. But, it is possible to quantify the affect.

Based on the above discussion, and from standpoints of both engineering and economy, it is imperative to replace the Kafue Road Bridge as quickly as possible. In selecting the bridge type, features of Zambia as a land-locked conutry shall be wholly considered.

Reconstruction of the bridge will bring improvement of bridge traffic, enable coping with increasing traffic volume, and consequently contribute to development of Zambian industries.

Table 1　STUDY FLOW CHART





ELEVATION OF KAFUE ROAD BRIDGE

Guage Hight;Port Elizabeth Datum

Fig. 1

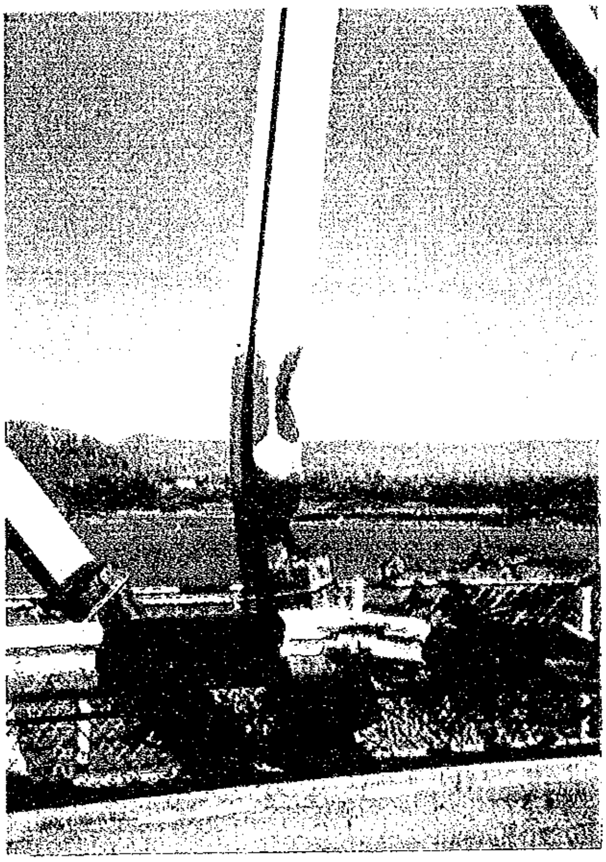


Fig. 3 Buckled Vertical

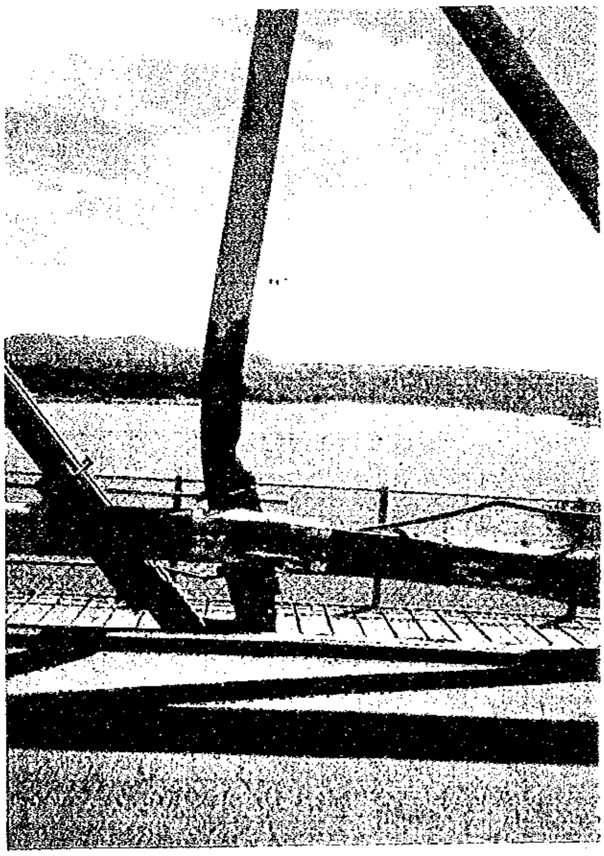


Fig. 4 Buckled Vertical

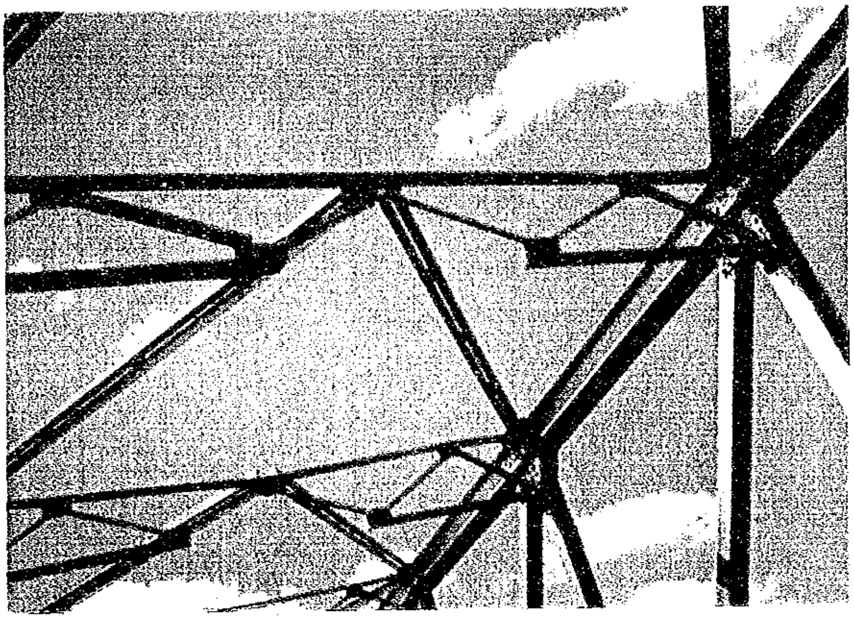


Fig. 5 Partly Missing Bracings

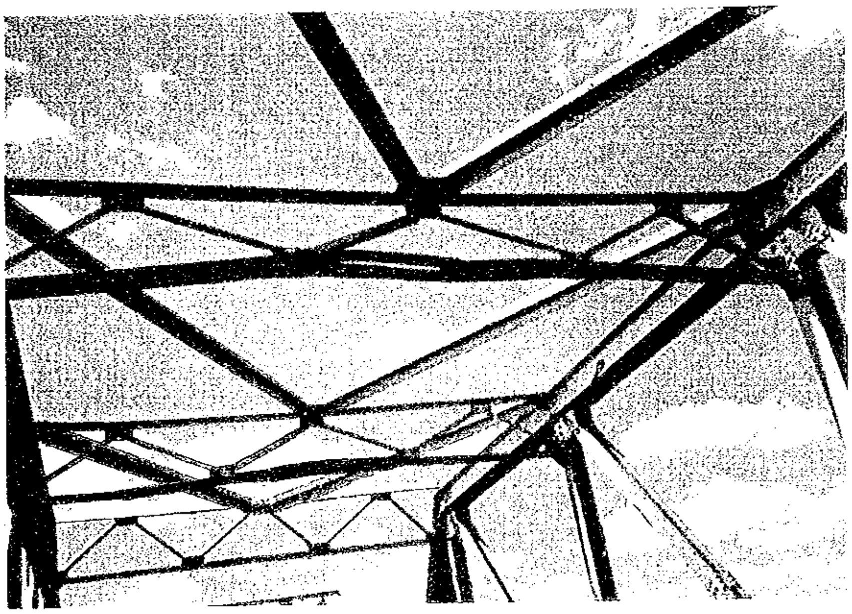


Fig. 6 Partly Missing Bracings

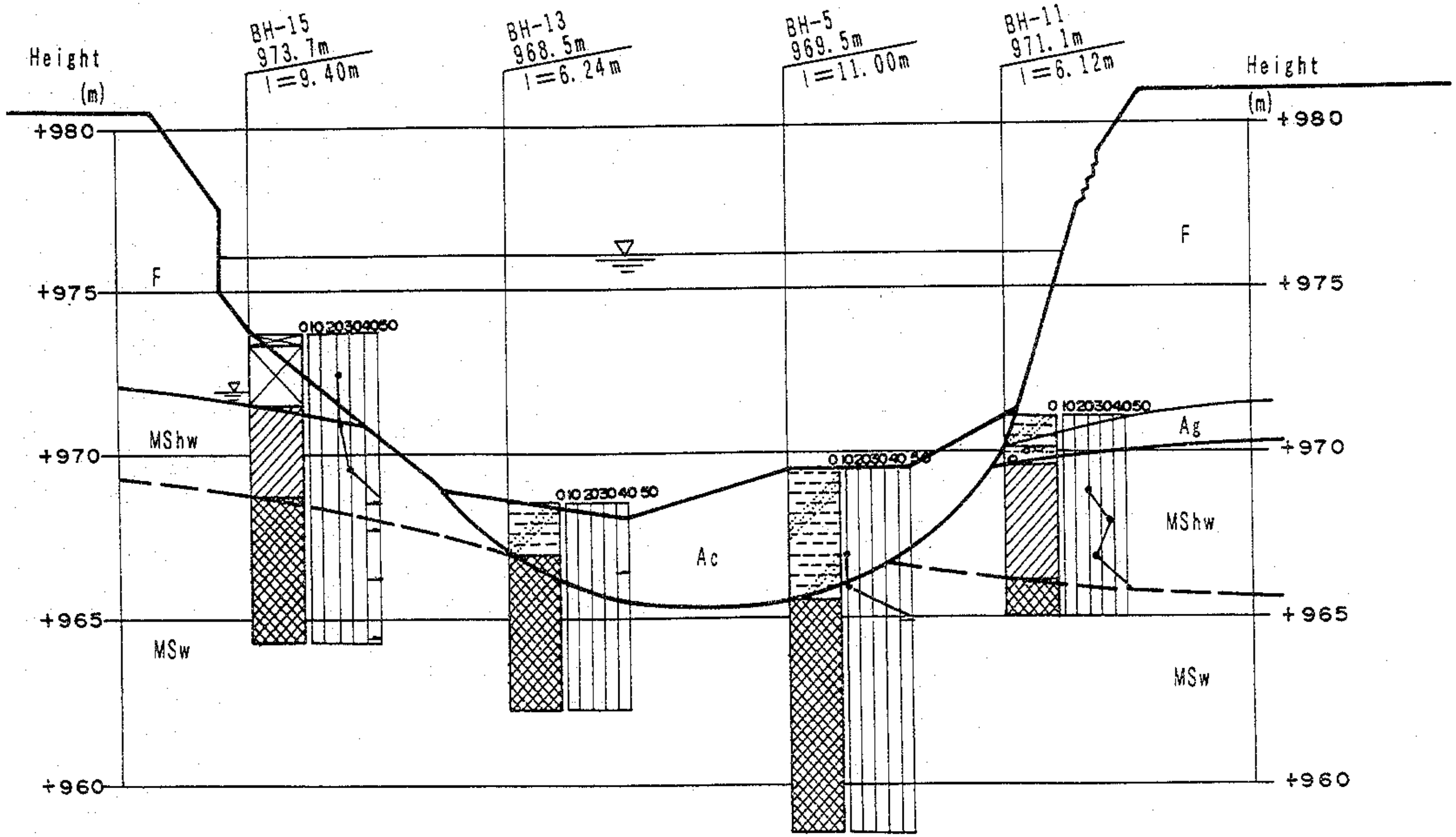


Fig. 7

GROUND CONDITION
ALONG EXISTING ALIGNMENT

Legend

F : Fill
Ac : Alluvial Clay
Ag : Alluvial Gravel
MShw : Heavily Weathered Mudstone to Sandstone
MSw : Weathered Mudstone to Sandstone

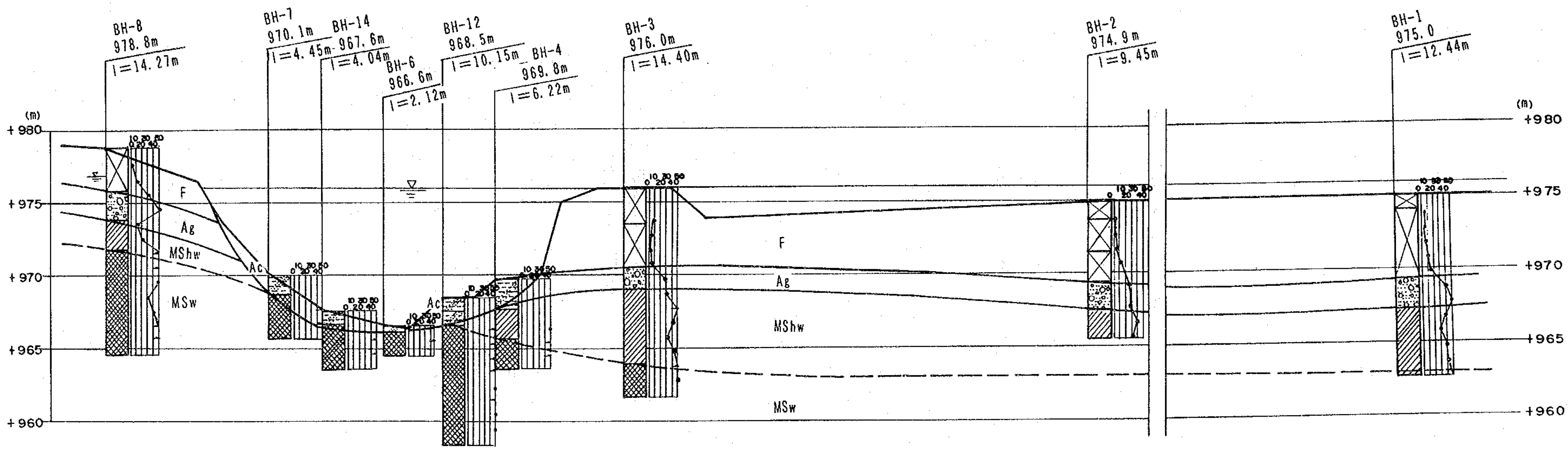


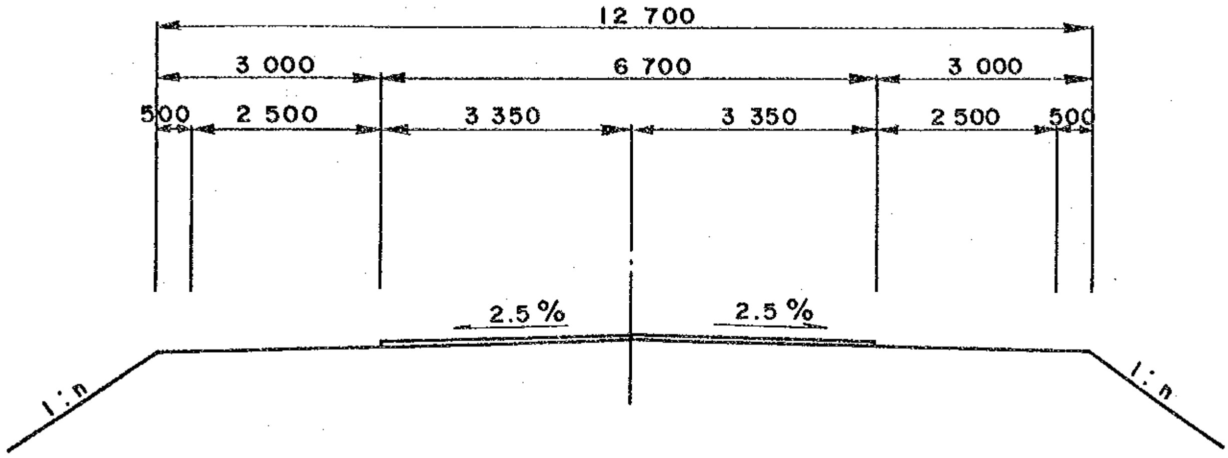
Fig. 8

GROUND CONDITION
ALONG NEW ALIGNMENT

Legend

F :Fill
Ac :Alluvial Clay
Ag :Alluvial Gravel
MShw:Heavily Weathered Mudstone to Sandstone
MSw :Weathered Mudstone to Sandstone

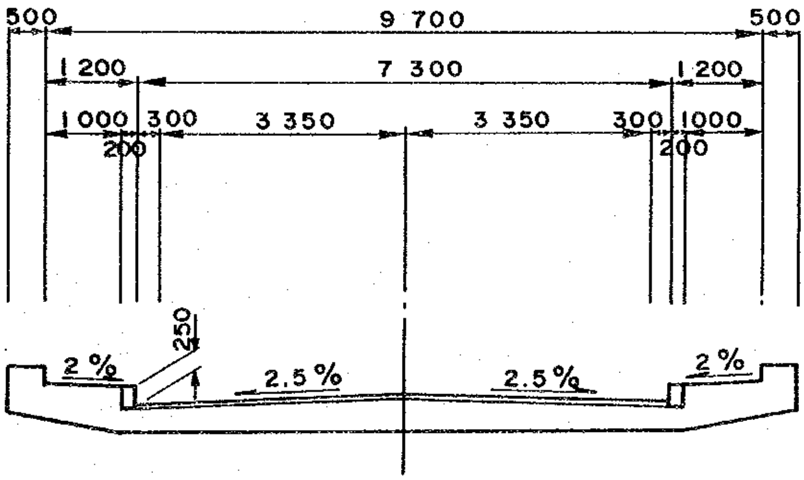
Scale V=1:200
H=1:1000



n=2, Fills over 3 m in height

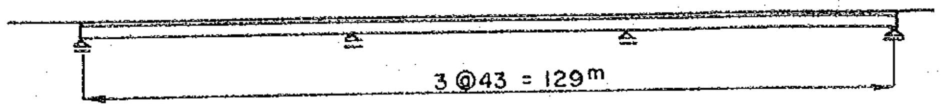
n=4, Below 3 m in height

Approach Embankment

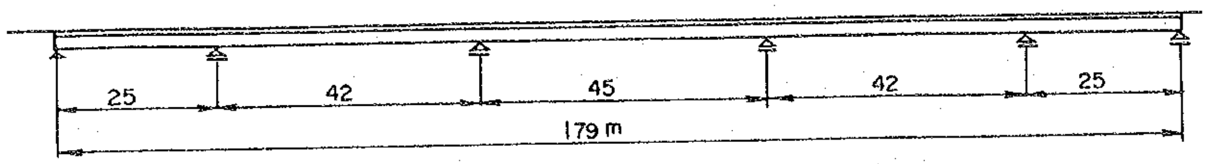


Bridge

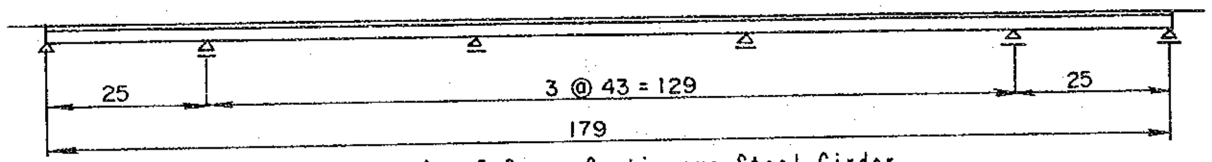
Fig. 9 TYPICAL CROSS SECTION



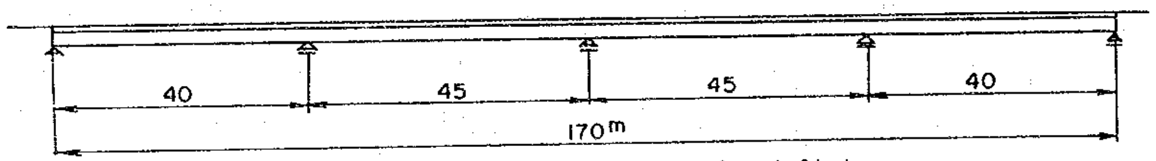
Scheme 1 3-Spans Continuous Steel Girder



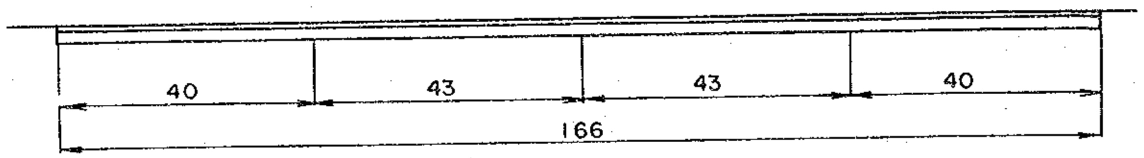
Scheme 2 5-Spans Continuous Steel Girder



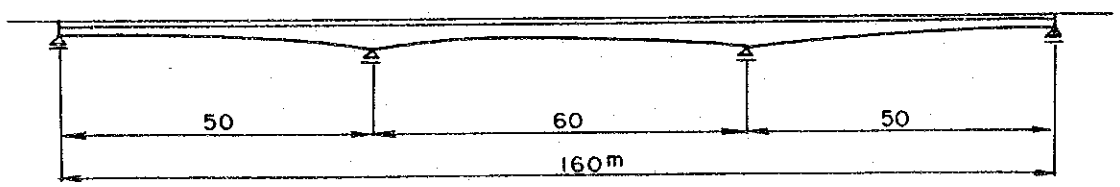
Scheme 3 5-Spans Continuous Steel Girder



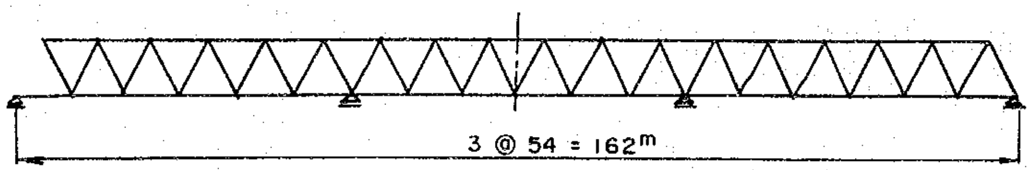
Scheme 4 4-Spans Continuous Steel Girder



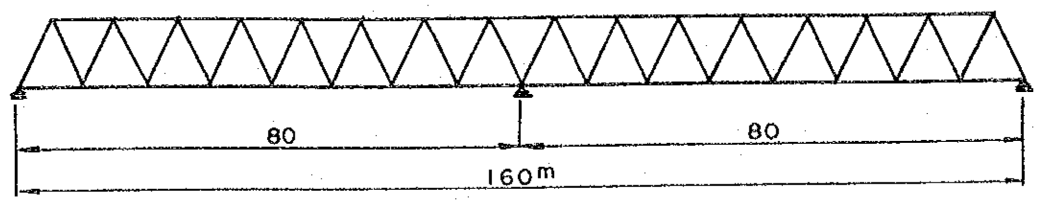
Scheme 5 4-Spans Continuous Steel Girder



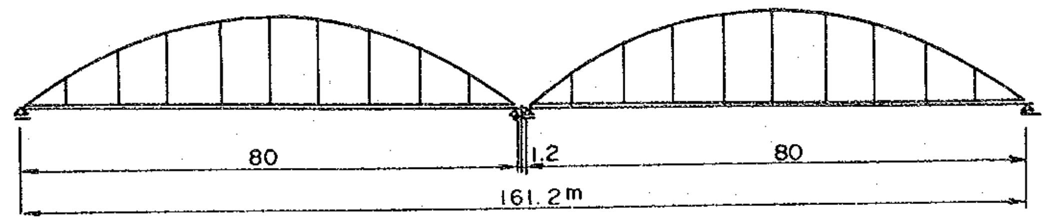
Scheme 6 3-Spans Continuous Steel Girder



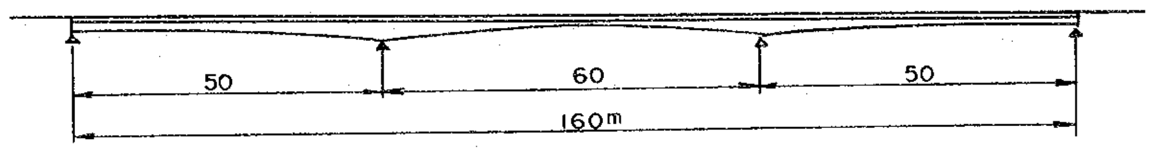
Scheme 7 3-Spans Continuous Truss



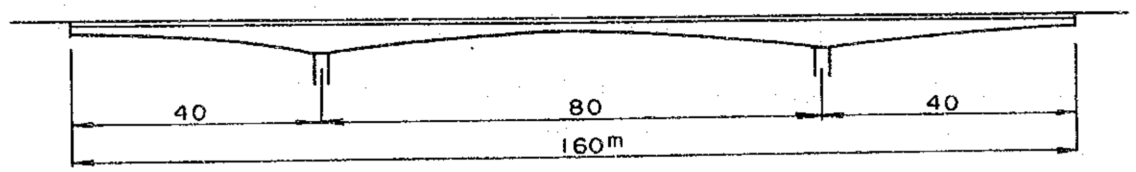
Scheme 8 2-Spans Continuous Truss



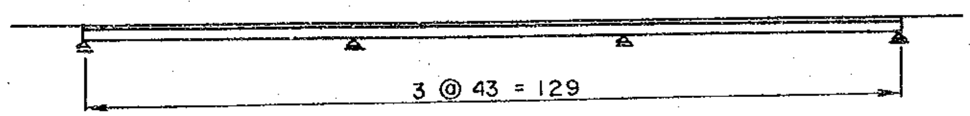
Scheme 9 2-Spans Steel Arch



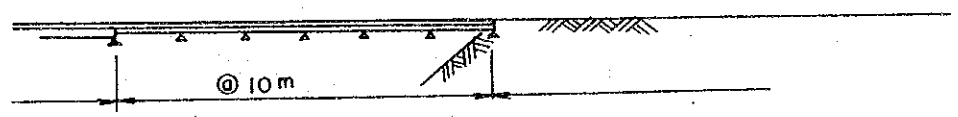
Scheme 10 3-Spans P.C. Girder



Scheme 11 3-Spans P.C. Girder



Scheme 12 3-Spans P.C. Girder



Scheme 13 Viaduct and Aproach Embankment

Fig. 10 ALTERNATIVE SCHEMES

Table 2 SUMMARY FOR SCREENING OF ALTERNATIVE SCHEMES

Good ○ Fair □ Poor △

Scheme	Type	Length of Bridge	Max. Span Length	Alignment Corres-ponded	Height of Abutment (m)	Number of Pier in Water	Eco-nomy	Dura-bility	Safety on Const.	Mainte-nance	Others	Evalu-ation
1	3-Spans Steel Girder	129m	43m	new/exist.	13m	2	○	○	△	Enbankment to be settled for new alignemnt		○
2	5-Spans Steel Girder	179m	45m	new	6m	3	□	○	○	To be care settlement of embankment	Restriction of Pier Location	
3	5-Spans Steel Girder	179m	43m	new	6m	3	○	○	○	do	do	○
4	4-Spans Steel Girder	170m	45m	(new)/exist.	7m	3	○	○	○			
5	4-Spans Steel Girder	166m	43m	(new)/exist.	8m	3	○	○	○			○
6	3-Spans Steel Girder	160m	60m	(new)/exist.	8m	2	△	○	○			○
7	3-Spans Steel Truss	162m	54m	(new)/exist.	8m	2	□	□	□			
8	2-Spans Steel Truss	160m	80m	(new)/exist.	8m	2	△	△	△			
9	2-Spans Steel Arch	161.2m	80m	(new)/exist.	8m	1	△	△	△			
10	3-Spans P.C. Girder	160m	60m	(new)/exist.	8m	2	△	△	△	Free		
11	3-Spans P.C. Girder	160m	80m	(new)/exist.	8m	2	△	△	△	Free		
12	3-Spans P.C. Girder	129m	43m	new/exist.	13m	2	○	○	△	Free		

Note : (new) designates that Schemes 4 through 12 can also be applied to new alignment, provided existing piers are demolished.

Table 3 COMPARISON OF ALTERNATIVES

Alter-native	Alignment Corresponded	Spans and Structural Type	Length of Project Road	Construc-tion Cost	Construc-tion Period (Months)	Restriction of Pier Location	River Width	Workability	Others	Evalua-tion
A	Existing	40+43+43+40=166m 4-Spans Continuous Steel Plate Girder	0.95Km	○	23	Nil	165m	good	Entail dismantling of existing superstructure	◎
B	Existing	3×43=129m 3-Spans Continuous Steel Plate Girder	0.95Km	○	22	Nil	128m	Cofferdam and Sealing to leak water	do	○
C	New	3×43=129m 3-Spans Continuous Steel Plate Girder	1.90Km	△	23	To keep Stream Line	128m	do	Re-routing of Tel. Line. Req. care for settle-of embankment	○
D	New	25+3×43+25=179m 5-Spans Continuous Steel Plate Girder	1.90Km	△	24	do	168m	good	do	△
E	New	50+60+50=160m 3-Spans Continuous Steel Plate Girder	1.90Km	×	24	do	159m	good	do	△

Note; ◎ Excellent
○ Good
△ Fair
× Poor

Table 4 Quantity of Superstructure

(1) Steel Weight	
1) Main Structure	
Main Girder	258.8 ton
Cross beam	11.4
Sway Bracing	12.8
Lateral Bracing	10.0
Bearing	10.5
Sub total	303.5 ton
2) Accessary	
Expansion Joint	6.2 ton
Drainage System	8.4
Hand Rail	13.2
Sub total	27.8 ton
3) Total Steel Weight	331.3 ton
(2) Material Area	
1) Pavement Area	
Footpath (3.0 cm thick)	324.0 m^2
Carriageway (7.0 cm thick)	1181.0 m^2
2) Concrete	
Concrete Volume of slab	542.0 m^3
Concrete Volume of mount-up footpath	104.0 m^3
Mould Area	1915.0 m^2
Weight of Steel Reinforced Bar	98.6 ton
3) Painting Area	4834.0 m^2

Table 5 Quantity of Substructure and Foundation

(1) Footing and Shaft

Item	Type	Unit	Q'ty
concrete placement	Footing and shaft (σ_{CK}=210kg/cm^2)	m^3	1391.8
	Leveling (σ_{CK}=180 ")	m^3	22.8
Framework	Footing and shaft	m^2	2375.7
	Leveling	m^2	8.5
Work Platforms	H ≥ 8 m	m^2	1765.7
Supportings	H < 10 m	m^3	773.3
Reinforce-ment	SD30	kg	85067.5
Earthwork	Excavation	m^3	2971.1
	Surplus Soil	m^3	437.3
	Backfill	m^3	139.6

(2) Steel Pile

Item	Type	Unit	Q'ty
Steep pipe	φ1000×22 SKK41	kg	132980
Filled concrete	σ_{CK}=210 kg/cm^2	m^3	177.6

Table 6 Quantity of Approach Roads

Work Item		Quantity	Note
1. Excavation		1,467.0 m^3	
2. Embankment		8,048.6 m^3	
3. Step Excavation	(left)	640.0 m^3	
	(right)	1,100.0 m^3	
4. Reclamation	(left)	801.6 m^3	
	(right)	1,085.6 m^3	
5. Slope Protection	(left)	2,657.5 m^3	
	(right)	3,364.5 m^3	
6. Pavement			
6-1 Surface Course	(Roadway)	5,278.9 m^2	2ST(*1)
	(Shoulder)	3,939.5 m^2	SST(*2)
6-2 Base Course	(left)	3,597.0 m^2	
	(right)	3,625.5 m^2	
6-3 Subbase Course	(left)	3,208.5 m^2	
	(right)	3,241.0 m^2	

(Notes) 2ST : Double Surface Treatment
SST : Single Surface Treatment

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