SATHORN BRIDGE PROJECT
BANGKOK THAILAND

FEASIBILITY REPORT

OVERSEAS TECHNICAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

MARCH 1970

FOREWORD

The Government of Japan, in response to the request of the Government of Thailand, entrusted the Overseas Technical Cooperation Agency with the implementation of surveys on the feasibility of the Sathorn Bridge Project.

The Overseas Technical Cooperation Agency, with fully recognizing the importance of the proposed bridge construction project, organized a survey team comprising specialists of transportation and bridge construction headed by Mr. Sadamu Mino, the Technical Counsellor of the Japan Public Highway Corporation and sent it to Thailand on two occasions.

In close cooperation with the Royal Thai Government, the team carried out the field survey works in various fields covering traffic and economic investigations and structural design of bridge.

In Japan, meanwhile, the committee for this project was organized to make valuable suggestions and advices to the team on the prospects of future traffic pattern in Bangkok-Thon Buri Metropolitan Area, evaluation of the impact of the proposed bridge, studies on the bridge structures and estimation of its construction cost. Result of the field surveys and recommendations of the committee have been fully incorporated into this report.

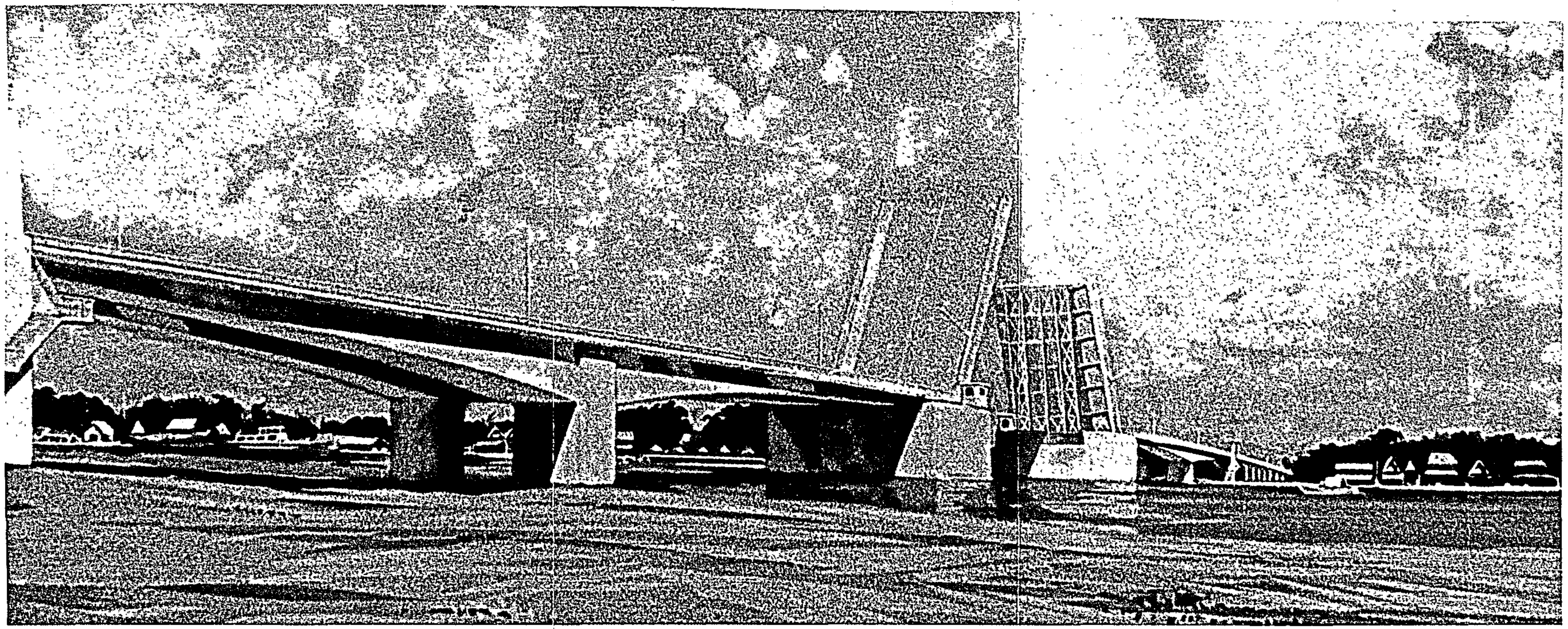
I sincerely hope that the recent survey will contribute to further development of the Bangkok-Thon Buri Metropolitan Area and at the same time, promote goodwill between Thailand and Japan.

Finally, I take this opportunity to express my hearty gratitude to officials of the Royal Thai Government and the Japanese Embassy in Thailand as well as the Japanese Government Agencies and the consultants companies.

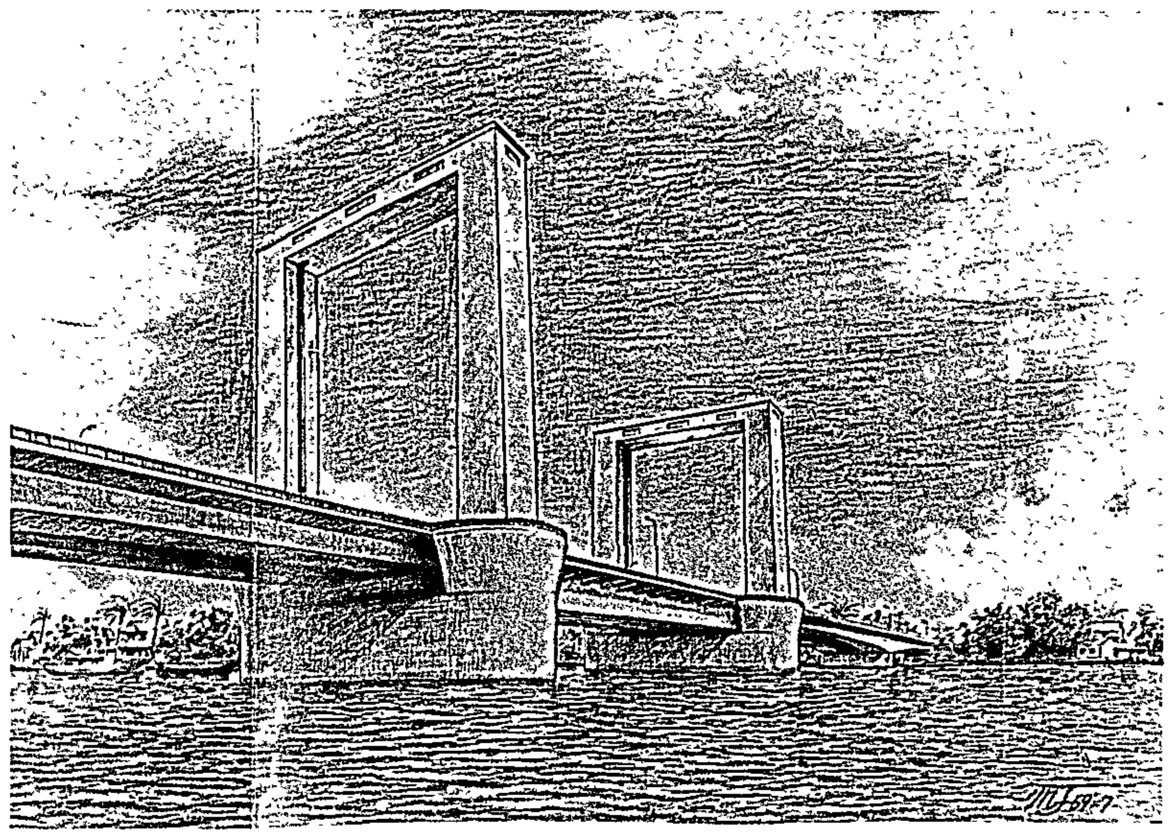
March, 1970

K. Tatsuke

Keiichi Tatsuke
Director General
Overseas Technical Cooperation Agency
Tokyo, Japan



Artist's View of the Sathorn Bridge with Bascule Type



Artist's View of the Sathorn Bridge
with Lift Type

CONTENTS

TABLES AND FIGURES

TABLES

FIGURES

INTRODUCTION

In recent years, the City of Bangkok, the capital city of Thailand, has made remarkable development to grow into a metropolitan area with the City of Thon Buri adjoining it across the Mae Nam Chao Phraya. With this, the traffic between these cities increased so rapidly that the existing four bridges over the river have become unable to cope with it.

For the purpose of solving the problem, the Government of Thailand, who had previously formed a plan to provide a bridge at Tha Chang site with the technical cooperation of the Government of Japan, recognized the importance of constructing another bridge and requested to the latter government to render further technical cooperation for surveying and planning of the project in a letter dated May 29, 1968.

Prior to this formal request, in April of the same year, the Government of Japan sent a preparatory survey team headed by Mr. Mitsuo Nishino who, having carried out a field survey, made recommendations the nucleus of which was to select the Sathorn site as a suitable point to construct a new bridge. The Government of Thailand decided to make it their policy to provide the bridge at the said point in compliance with recommendations.

It was followed by two field surveys to examine the feasibility of the bridge and to draw up its preliminary design. The First Survey Team who stayed in Bangkok for fourty three days from March 2 to April 13, 1969, conducted traffic surveys and economic investigations to grasp the realities of the traffic and visualize its future pattern in Bangkok–Thon Buri Metropolitan Area. They had a preliminary discussion with the Department of Public and Municipal Work, the Government of Thailand and other authorities on the basic requirements of the bridge construction and other matters as well.

The Second Survey Team visited Bangkok for fifteen days from August 13 to 27 of the same year to continue the field investigations into the problems of the structural design and construction of the bridge and discussed the issues with the concerned authorities of the Government of Thailand. On the basis of their findings, the preliminary design of the Sathorn Br. and the feasibility of its construction were examined after their return to Japan to make recommendations which are described in the present report.

Survey Staffs were as follows:

First Survey Team (March - April, 1969)

Leader	Sadamu Mino	(Technical Counsellor, Japan Highway Public Corporation)
Members	Toshiro Fukuyama	(President, Fukuyama Consultant Co., Ltd.)
	Yukitaka Uemae	(Chief of the Second Construction Dept., Tokyo Expressway Public Corporation)
	Akira Ishido	(Chief of the Second Planning Section, Planning Dept., Tokyo Expressway Public Corporation)

	Masaya Tokumaru	(Operations Section, Development Surveys Division, Japan Overseas Technical Cooperation Agency)
	Toru Ida	(Director, Fukuyama Consultant Co., Ltd.)
	Junji Hoshina	(Economic Research Section, Japan Highway Public Corporation)
	Koryo Mizota	(Fukuyama Consultant Co., Ltd.)
	Kunihiko Sawano	(Fukuyama Consultant Co., Ltd.)

Second Survey Team (sent for August, 1969)

Leader	Sadamu Mino	(Technical Counsellor, Japan Highway Public Corporation)
Members	Osamitsu Tamano	(Chief of the First Engineering Section, Engineering Dept., Tokyo Expressway Public Corporation)
	Shohei Nakamura	(Chief of the Second Designing Section, Engineering Dept., Tokyo Expressway Public Corporation)
	Hiroyuki Sawai	(Assistant Chief of the Local Road Section, Road Bureau, Ministry of Construction)
	Masaya Tokumaru	(Operations Section, Development Surveys Division, Japan Overseas Technical Cooperation Agency)

The present report is composed of three chapters. The second chapter deals with the role and effect of the Sathorn Bridge appraised on the basis of the forecast of future traffic in the Bangkok–Thon Buri Metropolitan Area and some problems related to the future planning of the road network. The third chapter treats the selection of the structural types of the bridge and its approaches as well as estimated costs of their construction. The findings and summary of these investigations and considerations are put together with the recommendations to the Government of Thailand shown in the first chapter. The details of the traffic survey and the forecast of the future traffic on which the present plans have been based are to be compiled in a separate report for future reference for the Government of Thailand.

Mention should be made of the English transliteration of Thai's proper nouns. There are many ways of expressing Thai in English but none of them is yet authorized. However, the following rules are applied in the present report.

The names of places, bridges and roads in and around Bangkok and Thon Buri are expressed in accordance with the map on a scale of 1 : 12,500. Series L 904, published by the Royal Thai Survey Department, with the following exceptions:

Spelling used on the map	Spelling used in the report
Saphan Phraram Hok	Rama 6 Bridge
Saphan Krung Thon	Krung Thon Bridge
Saphan Phra Buddha Yodfa	Memorial Bridge
Phra Ram Si	Rama 4
Phra Ram 1	Rama 1
Sathon	Sathorn

The spellings of "Changwat" and "Amphoe" are in conformity with those used in the Changwat–Amphoe Statistical Directory published by the Department of Local Administration, USOM and the National Statistical Office.

The bridges planned at Tha Chang site and dealt with in the present report are shown respectively as the "Tha Chang Bridge" and the "Sathorn Bridge" in accordance with the names given by the Department of Public and Municipal Works, the Government of Thailand.

ACKNOWLEDGEMENT

It would not have been possible to complete the feasibility survey of the Sathorn Br. Project so satisfactorily without the close cooperation of the Public and Municipal Works Department, Ministry of Interior of the Government of Thailand. We express our profound gratitude to Mr. Kanjana Hengsuvanij, Director-General of the Department, the members of the Planning Committee headed by Mr. Damrong Cholvijarn, Deputy-Director of the Department (present Director-General), and the members of the Engineering Committee headed by Mr. Sahat Sartnurak, the Chief Engineer of the same Department. Special mention must be made of the exceptional assistance given by Messrs. Tonchul Singhakul, Suebsri Camurai and Vichit Nutasara of the Planning Division of the above mentioned Department.

We extend our thanks to many officers of the Ministry of National Development, the Ministry of Transportation and the City of Bangkok who gave us much advice and data to carry out our surveys; among who the prominent persons are:

Ministry of National Development

Mr. Xujati Pramoolpol	Deputy Director-General, Department of Technical and Economic Co-operation
Mr. Uthai Voodhigula	Director-General of the Highway Department
Mr. Chaleo Vajrabukka	Deputy Director-General of the Highway Department (present Director-General)
Mr. Chamlong Saligupta	Deputy Director-General of the Highway Department

Ministry of Communications

Dr. Sirilak Chandrangsu	Undersecretary of State for Communications
Dr. Gun Nagamati	Deputy Director-General of the Land Transportation Department

Bangkok City

Mr. Prasert Navarat	Chief of the City Planning Division
Miss Arporn Chanchreonsook	Chief of the Planning Section, City Planning Division

We also extend our thanks to the Port & Harbor Department, Ministry of Communications, who cooperated with us in carrying out the ferry traffic survey and the river survey of the Mae Nam Chao Phraya.

Finally, acknowledgement must be made also to the following officers of the private firms who helped us with the surveys.

Mr. Amnuay Poonpipatana	General Manager, The Concrete Products and Aggregate Co., Ltd.

Mr. Ferdinand Weber	Resident Manager, General Engineering Co.
Mr. Charles E. Kline	Camp, Dresser & McKee

CHAPTER 1 SUMMARY OF FINDINGS AND RECOMMENDATIONS

This chapter summarizes the essentials of and the recommendations based upon the present survey. As to more detailed descriptions of the supporting data, reference is made to the relevant chapter or section of this Report.

Road Traffic in the Bangkok-Thon Buri Metropolitan Area

(1) With the growth of the Bangkok-Thon Buri Metropolitan Area, the traffic generation will increase remarkably in its outlying regions.

Although the central business district of Bangkok, west of Khlong Padung Krung Kasem, that is three amphoes of Phra Nakhon, Pon Prap and Samphanthawong are the largest sources of traffic in the Bangkok-Thon Buri area at present, its noticeable growth is not expected in the future.

With the advance of their development Amp. Yan Nawa and Amp. Phra Khanong will become big sources of traffic comparable with the present central business district.

Traffic generation is likely to increase considerably in the Amphoes of Dusit and Bang Khen and the urban area of Thon Buri.

(2) Consequently, it is expected that the traffic will increase considerably in between the outlying regions of the Bangkok-Thon Buri Metropolitan Area; the fact suggests the necessity of ring roads in the Metropolitan Area.

Traffic across the Mae Nam Chao Phraya and how to cope with it

(3) According to the development of the Metropolitan Area, the traffic across the Mae Nam Chao Phraya is expected to increase more rapidly. The Sathorn Br. should be open for traffic by 1975 at the latest.

This is not only due to the increase in traffic between both cities but to the fact that the urban traffic within Bangkok will increasingly have to make a detour via Thon Buri in order to keep out of the congestion in the central business district.

Although the necessity for the Sathorn Br. is very pressing, its construction work will not be started before that of the Tha Chang Br., which is now arranged by the Government of Thailand.

The present survey has presumed that the Sathorn Br. will be open for service in 1975, and it is ascertained that the traffic demand will have been in a large amount by that time.

(4) Even after the completion of both the Tha Chang and Sathorn Bridges, the Memorial Br. will not lose its importance. However, the volume of traffic on the latter will scarcely increase any more because this bridge and its connecting road network on the Bangkok side are already carrying traffic to their full capacities. Widening of the Memorial Br. will not be effective unless some improvements are made on its connecting road network in the central business district of Bangkok.

(5) After the completion of the Sathorn Br., the traffic on the Krung Thep Br. will decrease temporarily, but the construction of its connecting road on the Bangkok side will increase traffic so much that this bridge should play an important role in the future.

(6) It is clear that the traffic corssing the river will increase rapidly in the future and this will necessitate the construction of two or three bridges in addition to those now projected.

The findings of the survey show that the capacities of every bridge including those being planned will become saturated toward 1980. Since construction of more bridges is closely related tothe future planning of the Metropolitan Area, it needs to be planned carefully on the basis of a full-scale traffic survey.

Plan of the Sathorn Bridge

(7) Not only does the Sathorn Br. connect the city center of Thon Buri with the growing southern part of Bangkok but it is a part of the inner ring road, which constitutes an artery to carry the traffic received from the Paktho Highway to the northeastern or eastern part of Bangkok.

(8) It is appropriate that the Sathorn Br. has a roadway of six lanes.

Although the future demand for traffic on the Sathorn Br. is fairly great, six lanes in both directions will be proper for the bridge in view of restrictions due to the structural requirements of the bridge and the environment along its connecting roads.

(9) Sathorn Rd. which is to be the approach to the Sathorn Br. on the Bangkok side should have eight lanes in all utilizing the existing Khlong Sathorn for an additional four lanes and be grade-separated from Charoen Krung Rd. so as not to connect them directly by ramps.

The traffic of Charoen Krung Rd. has already reached its capacity and it cannot receive any more traffic. In addition, it is very difficult to improve this road.

(10) The approach of the Sathorn Br. on the Thon Buri side should be provided with a ramp to connect it directly to Charoen Nakhon Rd. as well as should over-cross the latter with four lanes, and then extending westward as a surface road of six lanes at least it should connect with Phra Chao Taksin Rd. Also it is desirable to link it to Lat Ya Rd. with a branch road running out halfway of it.

It should be avoided to link the connecting road directly with the Big Circle carrys heavy traffic and is surrounded by densely built-up areas.

Type of the Sathorn Bridge

(11) The width of the Mae Nam Chao Phraya at Sathorn is about 220m. With due regards to the requirements for river navigation and conditions of the bridge construction it was decided to form the Sathorn Br. by five spans in all, having the overall length of 313.0m; three spans over the river portion will have the clear span of 60m respectively and two spans, each having the effective span of 45.5m, will be provided on the land portions on both sides of the former three.

The central span must be of a movable type so as to allow the navigation of large ships. Two spans on both its sides are required in order to have a clear span of 60m as well as to be built of concrete. The anchor spans of 45.5m are to be provided on the land portions in order to enable the erection of the prestressed concrete bridge by the cantilever construction method so that no water line will be interrupted due to the constructing work.

(12) A steel bridge of bascule type will be proper for the central span.

Reduction in the weight of the girders and the floor system and in the size of the mechanical components including the counter weight will be the points to be aimed at in preparing the detailed designs.

(13) The most suitable substructure for the central span is the caisson foundation. It is recommended to build concrete caissons on steel floating caissons at the sites. The pneumatic caisson method is suitable for sinking them.

(14) As for concrete superstructures of side spans, both PC T-rahmen and the two-span continuous PC girder are equally advantageous, although the former, that is T-rahmen, is slightly more economical than the latter.

The anchor spans on the land portions become necessary to enable the side spans over the river portion to be built as PC bridge by the cantilever construction. It is undeniable that they result in an increased construction cost.

(15) The caissons are recommended also for the substructures of the side spans. The caissons placed on artificial islands to be built in the river can be sunk by dredging or open excavation.

If the economics of work is taken into account, the caisson foundations are recommended for the substructures of the side spans because it is advantageous that they are the same as those of the central span. In this case, artificial islands can be built in the river because the water depth is shallow and interference with navigation seems to be negligible. The caissons placed on the islands will be sunk by dredging or open excavation.

(16) The elevated approaches on both banks leading to the Sathorn Br. should be constructed on the piers founded on PC piles. Superstructures are of simple T-girder, and an economical span length is 25m except those spans over Charoen Krung and Charoen Nakhon Rds.

(17) In drawing up working designs, regards must be paid especially to the following points.

a) Prior to drawing up the detailed designs, adequate boring exploration should be carried out to investigate the soil conditions at such pier location in the river.

b) The river width of the Mae Nam Chao Phraya is somewhat contracted at Sathorn. The preliminary designs show that the bridge piers reduce the river cross-section considerably and have not a little influence on the flowing water, which causes the danger of accelerating the scouring of the river bed. In order to minimize these adverse effects, it is necessary to make the piers as small as possible and to shape their horizontal cross-sections so as to minimize the flow resistance; also an adequate measure should be taken to prevent the river bed from scouring.

c) As for the movable central span, adoption of the I-section main girders as well as the open grating floor system should be reconsidered in order to reduce the weight, and endeavors should be made to reduce the dimensions of mechanical parts including the counter weight so that the piers which house them can be diminished in size as far as practicable.

d) The adoption of steel bridge for the side spans seems worthy of re-examination from the standpoint of reducing construction costs.

Economic Feasibility of the Sathorn Bridge Project

(18) Although the construction of the Sathorn Br. will involve a huge cost, it is a very beneficial project from the standpoint of national economy. In view of the potential traffic demand being very great for the Sathorn Br., it should be constructed at an early date.

According to a rough estimation, the total cost of the Sathorn Br. project including the connecting roads has been put at around ฿456,000,000. Whereas, the annual economic benefit in terms of only a part of direct benefits which are easily measurable is expected to reach a colossal sum of ฿213,000,000 as of 1975 when the bridge is scheduled to be open for traffic.

The cost-benefit ratio will be 3.6, if it is calculated by the ordinary method at an annual interest of 12 per cent prevailing at present in Thailand; which shows that this project is very beneficial.

As mentioned in (3) above, a great potential traffic demand on the Sathorn Br. underlines the need to implement this project at an early date.

CHAPTER 2 TRAFFIC PROBLEMS IN THE BANGKOK-THON BURI METROPOLITAN AREA AND THE SATHORN BRIDGE PROJECT

2-1 The Metropolitan Area

(1) Location

Bangkok is situated in the center of Thailand near the estuary of, and on the vast alluvial plain built up by the Mae Nam Chao Phraya. It has developed as the capital of the country since 1782 and is the center of politics, economics and culture. Thon Buri on the other side of the Mae Nam Chao Phraya is the former capital of the country and has developed as one body with Bangkok, constituting the Greater Bangkok.

These cities are the only great cities in Thailand and the present survey covers the Bangkok – Thon Buri Metropolitan Area including both cities and their suburbs.

Centering around these cities, there are various transportation facilities developed. Railways and roads run to every part of the country form Bangkok. The Don Muang International Airport is the center of both domestic and international air transport, and air routes radiate to various parts of Southeast Asia. The Port of Gangkok lying on the estuary of the Mae Nam Chao Phraya is the front door of Thailand's coast line and is conveniently connected with the northern and central parts of the country by boats.

(2) Area and Population

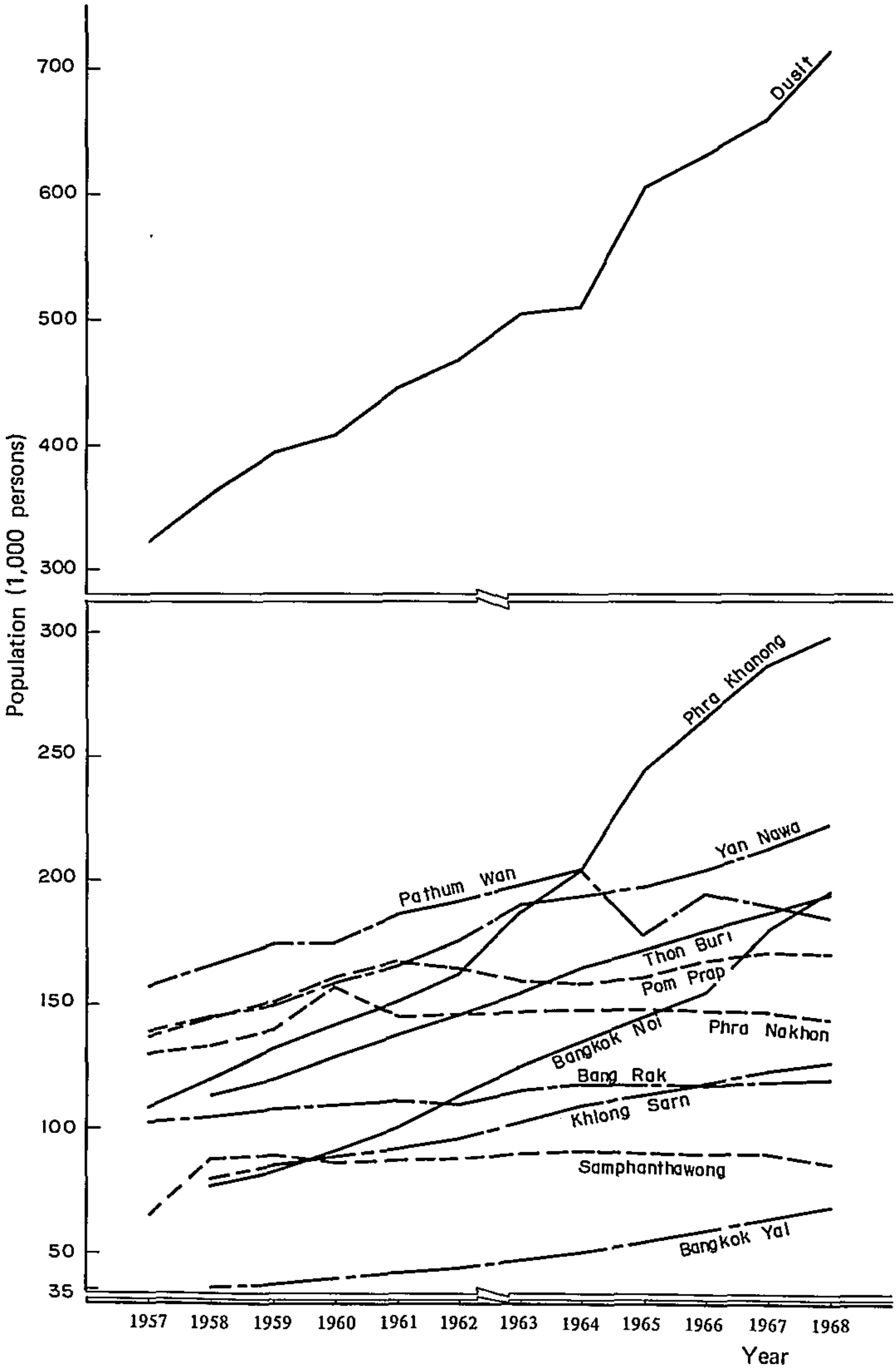
The area and population of whole Thailand and the cities of Bnagkok and Thon Buri are shown in Table 2-1-1, which indicates a fairly dense concentration of population in these cities. Fig. 2-1-1 shows the trend of population by Amphoes of both cities.

Table 2-1-1 Area and Population (1966)

	Area (km^2)	Population (1,000 persons)	Density (persons/ km^2)
Bangkok City	124.7	1,937	15,500
Thon Buri City	51.0	564	11,200
(1) Total	175.7	2,501	14,200
(2) Thailand	514,000	32,000	62
Rate (1)/(2)	0.034%	7.8%	—

Although the central business district of Bangkok City with the City Hall as its center, lying between Krung Kasem Rd. and the Mae Nam Chao Phraya (comprising Amp. Phra Nakkon, Amp. Pom Prap and Amp. Samphanthawong) is densely populated, the population of this area remains rather constant at this time in years. Instead, the increase in population is shifting to the outskirts of the Bangkok City and remarkable growth is apparent in the district centering around Phet Buri Rd., Sukhum Wit Rd. and Rama 4 Rd. (or Amp. Phra Khanong) in the east, and in the district comprising Phahon Yothin Rd., Mettraphap Rd. and Rama 5 Rd. (or Amp. Duist) in the north, and also in the Thon Buri City (See Feg. 2-1-2).

Fig. 2–1–1 ANNUAL POPULATION BY AMPHOES



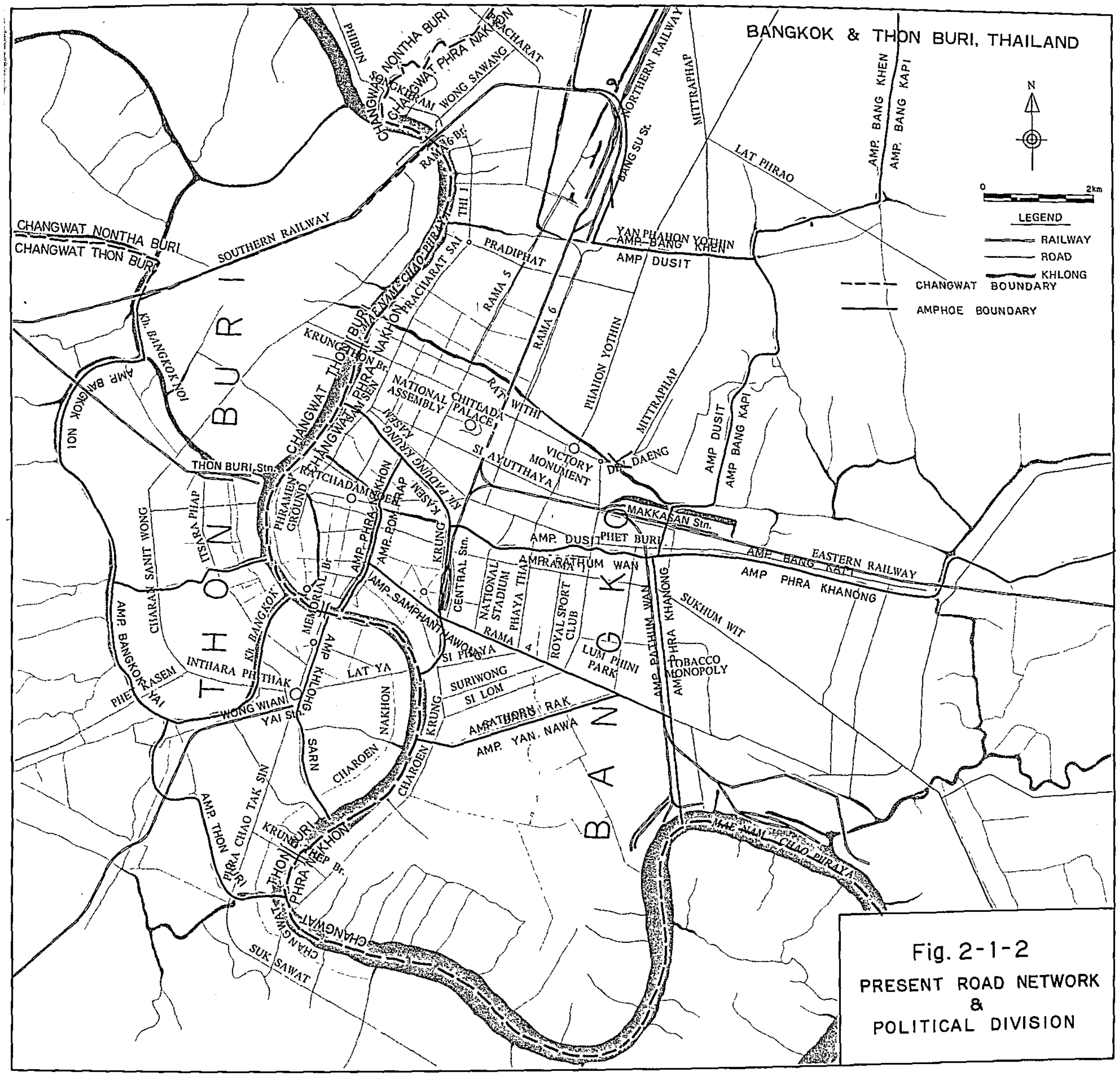


Fig. 2-1-2
PRESENT ROAD NETWORK
&
POLITICAL DIVISION

Fig. 2–1–3 LAND USE 1965

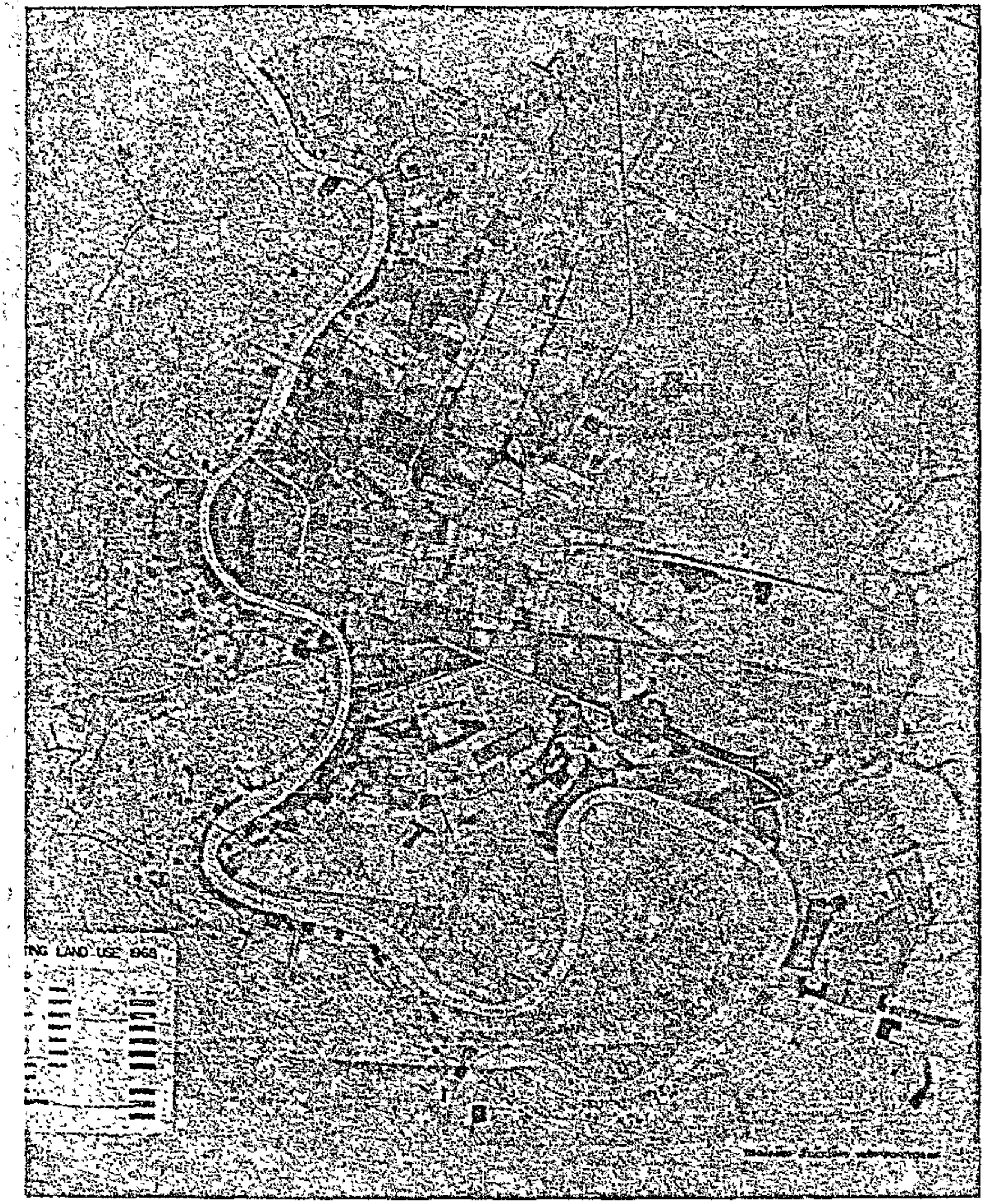
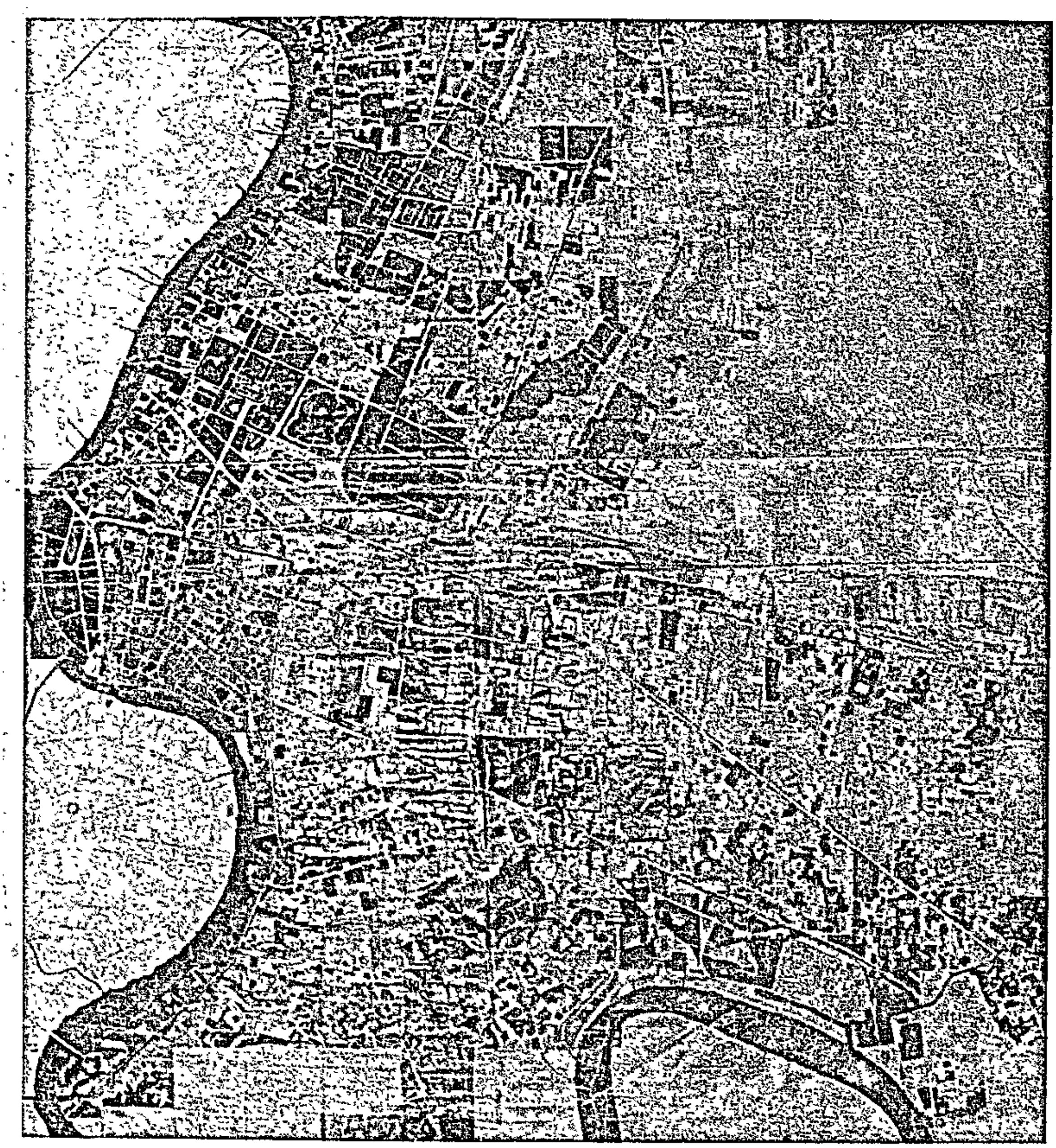


Fig. 2–1–4 LAND USE 1969



(3) Land Use

The present state of land use is shown in Figs. 2-1-3 and 2-1-4. From the regional point of view it may be summarized as follows.

The area lying between the City Office and Bangkok Central Station, that is Amp. Pom Prap and Amp. Samphanthawong have been developed as a commercial district, comprising commercial firms, wholesale traders, retail stores, and restaurants. This area shows a very high density of population reaching 7 - 8 thousand persons/km^2 and constitutes a fairly built-up commercial-residential district. Nevertheless, there have been no growth of population in recent years; this fact endorses the observation that this area has no more prospect to develop as things stand today.

The area adjustment to the above, lying between it and the Mae Nam Chao Phraya, that is Amp. Phra Nakhon comprises many government lots such as parks, royal places, government offices, schools and temples. If these circumstances are taken into account, it seems that its residential-commercial district has about the same population density as the above area, and that judging from this and the static population this area forms a long standing central business district of Bangkok in the same manner as the above area.

Amp. Pathum Wan and Amp. Bang Rak lying to the southeast of the three old central business districts have universities, parks and stadiums in addition to a residences areas. A strip of commercial district develops along the trunk road. With relatively high density, but without any significant growth of population, they make themselves stabilized areas.

As previously stated, Amp. Dusit and Amp. Phra Khanong are showing rapid growth in their population. The former, having a good number of government institutions and parks, has developed as a residential district. The latter has parks in addition to its industrial area as well as the Port of Bangkok with the rest being a residential district. Both of these areas having a lot of unused land and low density of population have prospect to develop for the future.

There are the government owned tobacco factory near by Rama 4 Rd. and the industrial areas near the Krung Thon Br. and on the upper stream side of the Krung Thep Br., both on the left bank of the Mae Nam Chao Phraya. The rest, other than these areas, has low density of population and is used as farm land and residential quarter.

In Thon Buri City, an industrial area streches from Khlong Bangkok Yai to downstream along the right bank of the Mae Nam Chao Phraya, and also a commercial district develops centering around the Big Circle (Wong Wian Yai) along the trunk roads. The rest of this area is used as orchard and farm lands dotted with residences. The density of population is still low as compared with that of Bangkok City, and its urbanization is expected in the future.

2-2 Transportation in the Metropolitan Area

(1) Outline

The Mae Nam Chao Phraya and a network of canals, or the Khlongs, spreading in all directions from it have played an important role as water transport routes for a long time. However, they have become one of the reasons why the development of land transportation in urban area has been held up. These days, traffic is considerably congested in the Metropolitan Area, with especially severe traffic jams during the rush hours in the morning and evening. This trend has been intensifying year by year and the need is felt keenly to take radical measures to meet the situation as soon as possible.

a) Roads

In Thailand, the improvement of roads has been promoted in recent years and the total length of the national and local roads reached 20,000 km with more than half of the national highways surfaced. With this improvement, motor vehicles have begun to play more and more an important role in inland transport. Roads are also the principal means of traffic in the Metropolitan Area and the recent acceleration of motorization has caused the rapid increase of traffic volume to result in a considerable congestion on the streets of the urban area. In particular, the Memorial Br. and its connecting street networks and intersections in the central business district have become almost been paralysed by traffic during the rush hours. The networks of bus service which are the typical means of transport for townspeople are well developed to cover almost the entire Metropolitan Area. But every bus is overcrowded with commuters during the rush hours and a limit of capacity is clearly seen in the existing transport system.

b) Railways

The railways service in Thailand is provided by the State Railway of Thailand with a route length of about 4,000km in total, as of 1968, rediating from Bangkok. Improvement of transport service is underway by modernization of facilities such as speed-up of trains chiefly by dieselization (See Table 2-2-1).

Table 2-2-1 Main Lines of the State Railway of Thailand

Lines	Operating km (km)
Northern Ry. (Bangkok – Chiangmai)	700
Northeastern Ry. (Bangkok – < Nongkai / Ubon)	1,100
Eastern Ry. (Bangkok – Cambodian border)	270
Southern Ry. (Bangkok –Malaysian border)	1,600
Other branch lines	520

In the Metropolitan Area, the only line across the Mae Nam Chao Phraya is the Southern Railway detoiring the city center toward the far north to the Rama 6 Br. Moreover, because of stations generally sparsely located and an insufficient number of trains operating the railways are not effective enough to meet the everyday traffic demand of the Metropolitan Area.

Although the State Railway of Thailand has a draft plan to extend the Mekhlong Line, now terminating at the Big Circle Station (Wong Wian Yai), to connect with the Eastern Railway across the Mae Nam Chao Phraya, its implementation is regarded as difficult because of the great investment in the construction of a bridge across the river and an elevated bridge over Khlong Padung Krung Kasem.

c) Waterways

Since the Metropolitan Area has grown and developed on the alluvial plain formed on the lower reaches of the Mae Nam Chao Phraya, water transport has played an important role as a convenient means of door to door transportation, as an effective means of transpotation serving rice mills, lumber mills and warehouses lining the Mae Nam Chao Phraya, and as a means for crossing a river having few bridges.

At present, passengers using ferries to cross the Mae Nam Chao Phraya are well over 160,000 persons a day. Water buses, water taxis and sampans operating in all directions on the Mae Nam Chao Phraya and its connecting canal networks are the essential means of transportation for the townspeople in their daily commuting.

d) Airways

The Don Muang International Airport being situated at about 17km north of Bangkok along the National Highway No. 5 is blessed with ideal conditions such as an airport and is the center of international air routes in the Southeast Asian region, with all the main international air lines serving it. In 1967, airplanes landing and taking off from this airport numbered about 35,000 and arriving and departing passengers were well over 900,000 persons (excluding through passengers). Thus the capacity of its existing facilities has already become saturated. Accordingly, a plan is now developing to construct the second international airport near Khlong Nong Nguhao at about 30 km to the east of Bangkok, with a total area of $24km^2$.

Domestic air routes radiate from Bangkok in all directions linking with main cities as do the railways.

Transportation between the city of Bangkok and the airport has recoursed almost entirely to motor vehicles.

(2) Traffic Surveys

a) Outline

The Japanese Survey Team carried out the traffic surveys to grasp the traffic situation in the Bangkok – Thon Buri Metropolitan Area and to make use of it as the basic data for estimating traffic volume in the future. At the same time, they made efforts to correct data to estimate the traffic volume as best as possible.

These surveys included an origin-destination survey (hereinafter referred to as OD survey) at 4 stations, a 12-hour traffic count at 39 stations, weekly traffic count at 3 stations, a travel-time study on 18 routes and a ferry passenger survey at 6 stations. Five officials from the Japanese Survey Team engaged exclusively in the suveys which took about six weeks, from February to April of 1969, including the preparatory period.

The Thai authorities assigned about ten engineers from the Department of Public and Municipal Works, who co-operated as liaison officers and supervisors at survey stations. In addition, two teachers of the Uthenthawai School of Building Construction were assigned to take charge of controlling about fifty students from that school who engaged in the survey work.

Table 2-2-2 and Fig. 2-2-1 show the summaries of these surveys, with references made to the separate report for the details of the surveys.

Hereinafter in this Report, the present situation of traffic in the cities of Bangkok and Thon Buri is considered and analyzed based on the findings of these surveys and the future volume of traffic is estimated.

b) Zoning

As stated above the cities of Bangkok and Thon Buri may be regarded as forming a Metropolitan area functioning as one city, although they are divided into two administrative districts. Therefore, traffic between these cities has a character of urban traffic and the Sathorn Br. is to be incorporated into a part of the road networks in these cities. In estimating the traffic volume on the Sathorn Br., it is necessary to give the entire picture of the traffic

Table 2-2-2 Traffic Survey conducted by the Japanese Survey Team

Type of Survey	Purpose	Method	Coverage	Items	Location of Survey Stations	Date (1969)	Remarks
OD survey	The most important and basic data for forecasting the traffic volume on the Sathorn Br. It is to assess the traffic generation of motor vehicles by zones and their OD distribution.	Roadside interview by random sampling	12-hour vihicular traffic across the Mae Nam Chao Phraya, excluding motor cycles and scheduled buses	Direction of passing vehicle, time of passing, type of vehicle, use of vehicle origin and destination	Memorial Br. Krung Thon Br. Krung Thep Br. Rama 6 Br.	Every Tuesday, Wednesday, Thursday and Friday between the 11th and 19th of March From 7:00 to 19:00 hour	No. of vehicles surveyed (sampling ratio) 25,223 (11.33%)
12-hour traffic count	Basic data to assess the traffic flow and traffic volume on each route and at each intersection in the area covered for estimation. Data at the survey stations provided on the screen lines were used as correcting values to estimate the complete OD table.	Manual count	12-hour vehicular traffic at selected points in the area covered for estimation	Hourly vehicular traffic by types and traveling directions	11 stations including 4 OD survey stations	Every Tuesday, Wednesday, Thursday and Friday between 11th and 25th of March From 7·00 to 19:00 hour	
				Hourly vehicular traffic by directions of all types (excluding motorcycles)	26 stations	Tuesday, Wednesday, Thursday and Friday between the 20th and 26th of March From 7:00 to 19:00 hour	
				Hourly vehicular traffic by directions at intersections	2 stations	26th (Wednesday) and 27th (Thursday) of March From 7:00 to 19:00 hour	
Weekly traffic count	Data on the weekly and 24-hourly variations in traffic volume. Daily traffic volume was calculated on this data	Automatic traffic counter	Vehicular traffic across the Mae Nam Chao Phraya	Hourly vehicular traffic by directions	Memorial Br.	From 3rd to 9th of June	
					Krung Thon Br.	From 1st to 7th of July	
					Krung Thep Br.	From 20th to 26th of June	
Travel-time study	To grasp the inter-.elation of the travelling speed and traffic volume of each section of the road network.	Average-speed technique		Travel time between main intersections, and stopping time	18 main routes	From 2nd to 10th of April	
Ferry passenger survey	To make clear whether passengers now using ferries to cross the Mae Nam Chao Phraya will be converted to those using motor vehicles after the bridges are constructed.	Manual count	Passengers using ferries at points near the proposed site of the Sathorn Br.	Hourly no. of ferry passengers by directions and service frequency of arriving and departing ferries	6 ferry stations between the Memorial Br. and the Krung Thep Br.	1st of April From 7 00 to 19:00 hour	No. of passengers surveyed 4,463 persons
		Interviews		Means of land transportation used by ferry passengers			

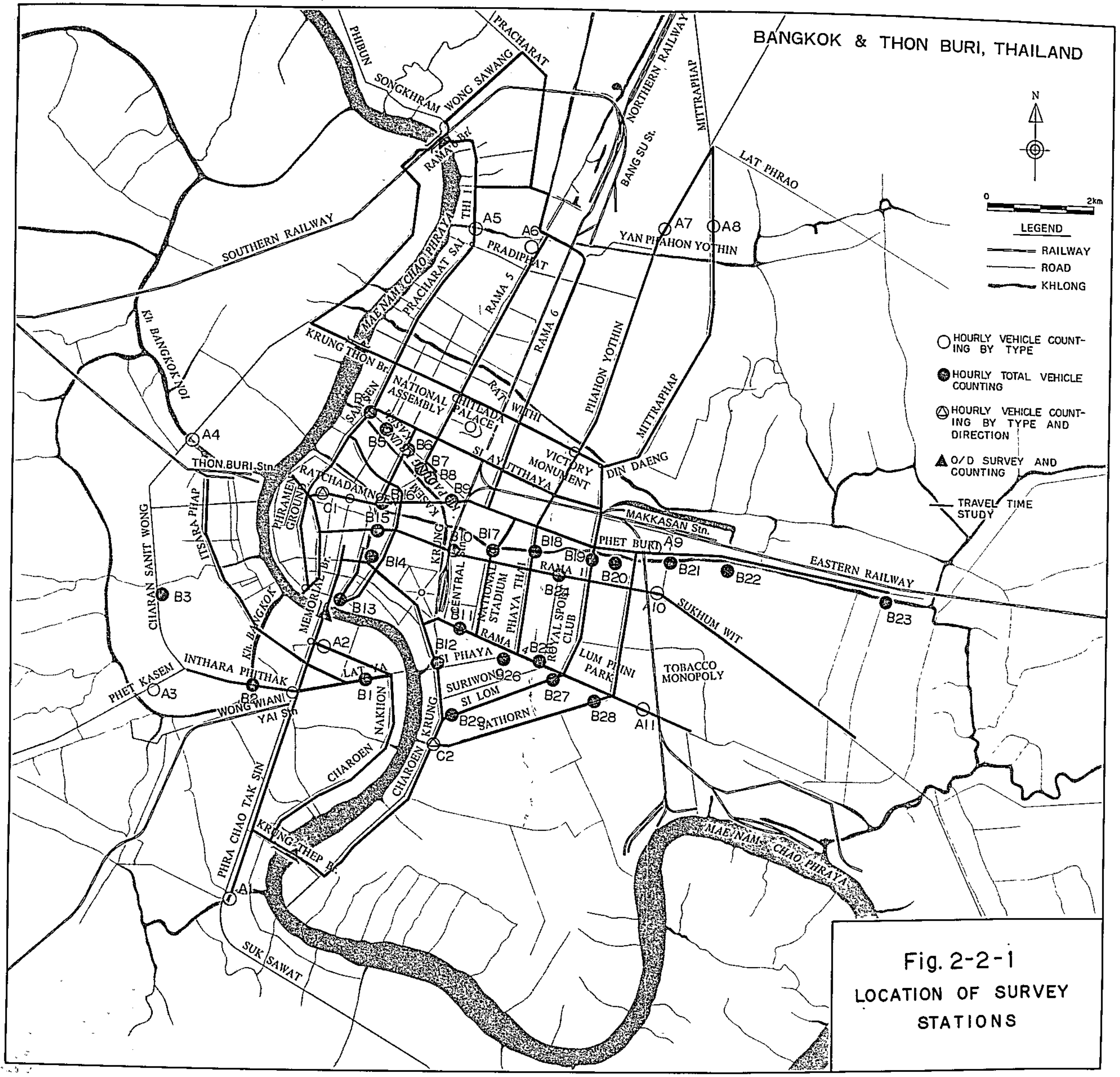


Fig. 2-2-1
LOCATION OF SURVEY STATIONS

in the Bangkok – Thon Buri Metropolitan Area.

From this point of view, the area covered was divided by the following lines so that the city areas of Bangkok and Thon Buri may be included in it.

The east part of the Mae Nam Chao Phraya (Bangkok side):
the north - the boundary between Cha. Phra Nakhon and Cha. Nontha Buri
the east - Khlong Song Khathiam and Khlong Phra Khanong
the south - Mae Nam Chao Phraya

The west part of the Mae Nam Chao Phraya (Thon Buri side):
the north - the boundary between Cha. Thon Buri and Cha. Nontha Buri
the west - the boundary of Amp. Bangkok Noi, Bangkok Yai and Thon Buri

In order to secure correspondence to the economic indices, the area covered for estimation enclosed with these boundaries were first divided into zones by Amphoes are administrative districts, the especially large Amp. Dusit was subdivided into 3 zones and Amp. Pathum Wan involving partially different land use was subdivided into 2 zones.

The traffic survey and the analysis of the present pattern of traffic were carried out in accordance with the above zoning. However, because of the fact that Amp. Yan Nawa and Amp. Bangkok Noi are too large and their specail development is expected and that Amp. Khlong Sarn is divided into north and south by the connecting road of the Sathorn Br., these three Amphoes were respectivley subdivided into 2 zones in estimating future traffic. As for details of zoning, reference is made to Fig. 2-2-2, Fig. 2-2-3 and Table 2-2-3.

(3) Road Traffic in the Metropolitan Area

a) Vehicle Registration

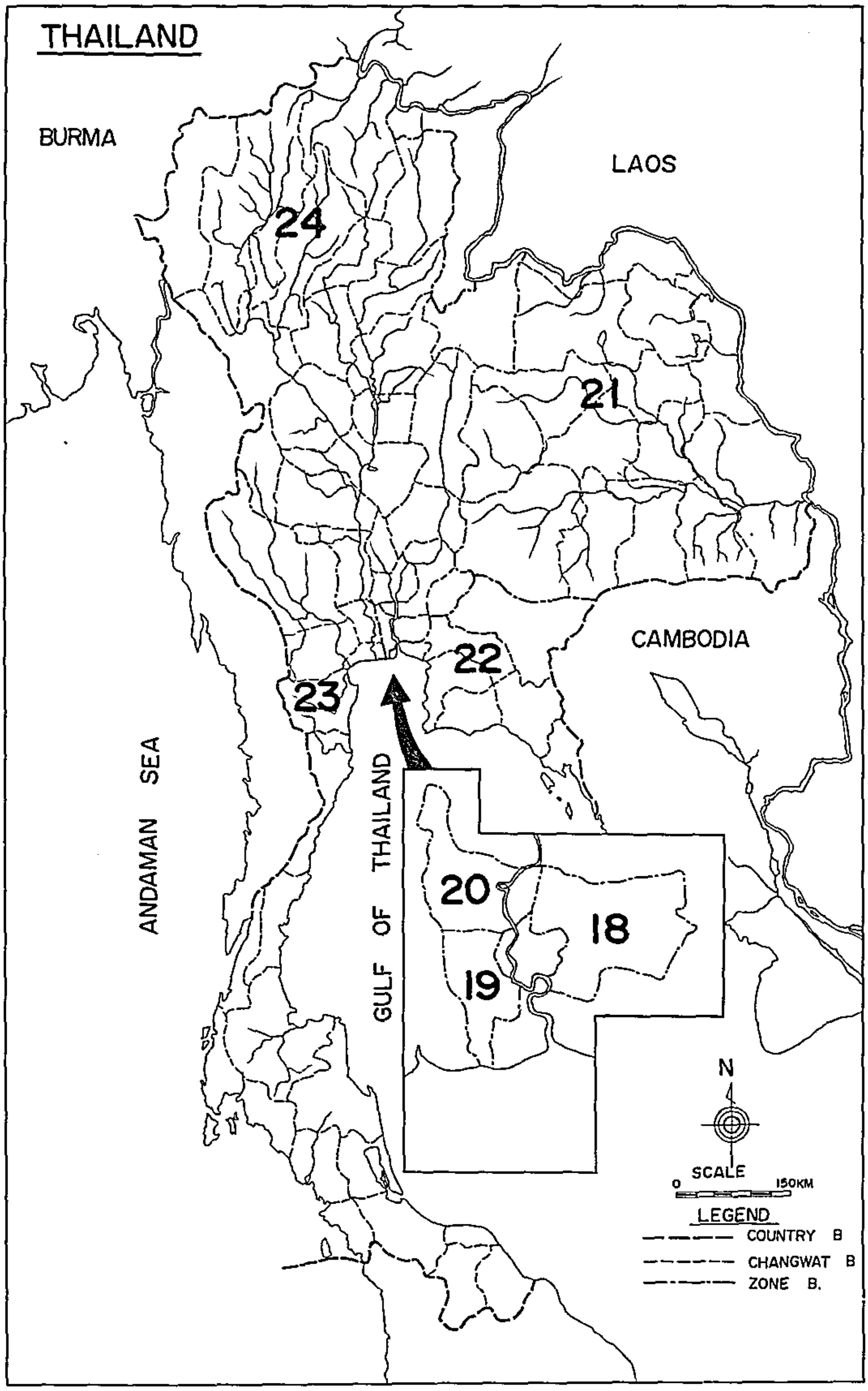
The number of registered vehicles in Bangkok and Thon Buri were around 230,000 in 1968, accounting for about one half of the total number in Thailand. This represented one vehicle per about 14 heads of total population of both cities. These areas have a high growth rate of vehicle registration and the said number increased four and half times in 10 years from 1958 to 1968; in other words, they have increased by more than 16% per annum (See Fig. 2-2-4).

b) Vehicle Type

The road traffic in the urban area is a mixed traffic of passenger cars, buses, large and small sized trucks, motorcycles and samlors (tricycles). The structural ratios of these vehicle classes worked out on the basis of the number of registered vehicles in 1968 are 50% for passenger cars, 25% for motorcycles, 20% for trucks and 5% for others including samlors. The changes in vehicle registration in 10 years from 1958 to 1968 as shown in the sequence of growth rate were 5.7 times for motorcycles, 4.5 times for passenger cars and 4.3 times for trucks.

In the actual road traffic, trucks accounted for one fourth of all the vehicles in every traffic count made by the Survey Team at stations on the Thon Buri side, showing the high industrial coloring of this city. Whereas, passenger cars accounted for more than half of all the vehicles at many stations in the eastern and northeastern parts of Bangkok, reflecting that they are residential areas and have the Don Muang Airport. The survey stations at the Memorial Br. and it vicinity counted less than 10% trucks of all passing vehicles due to the restriction imposed on the traffic of large sized trucks to cross the said bridge.

Fig. 2–2–2 ZONING



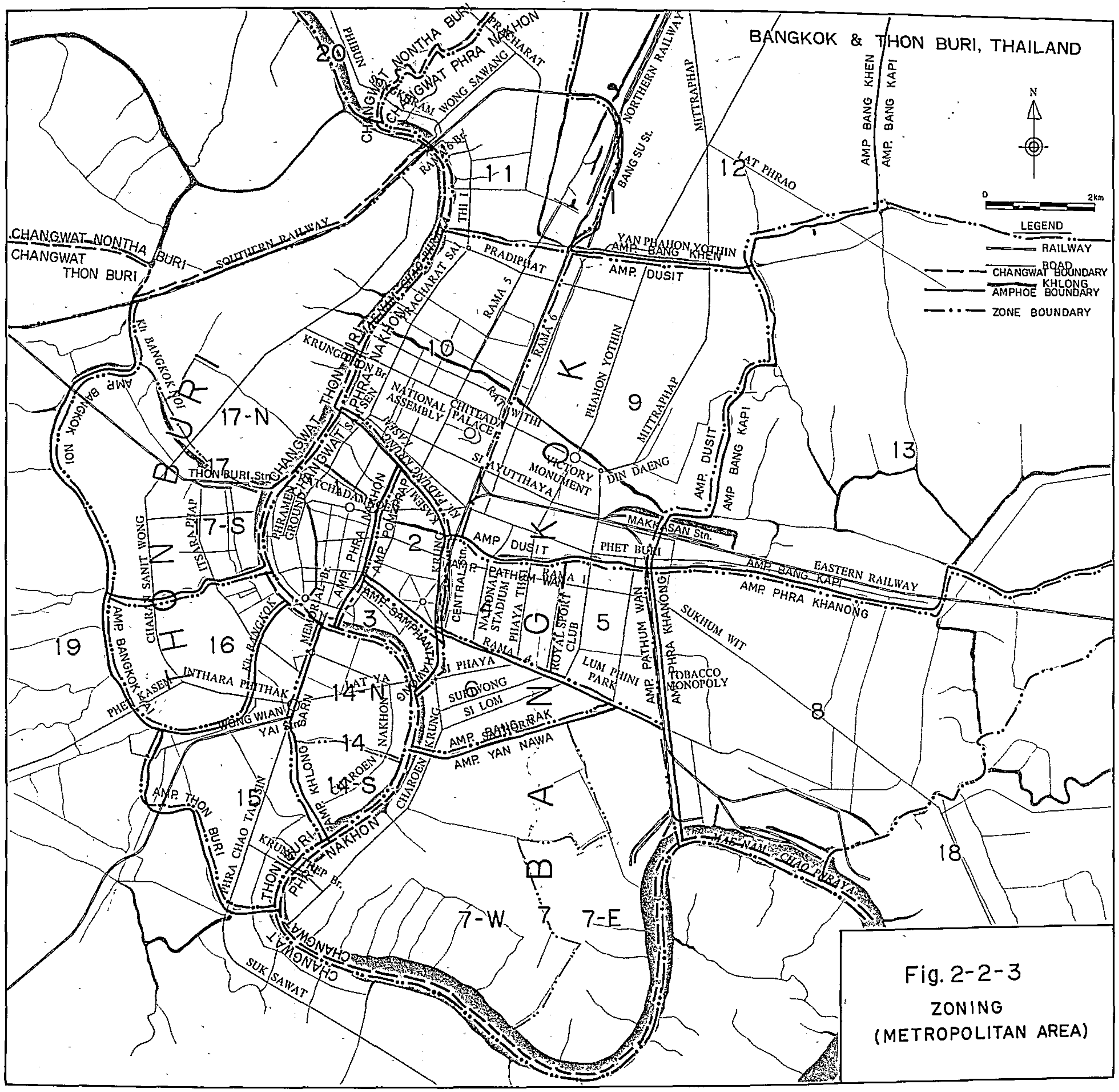


Fig. 2-2-3

ZONING

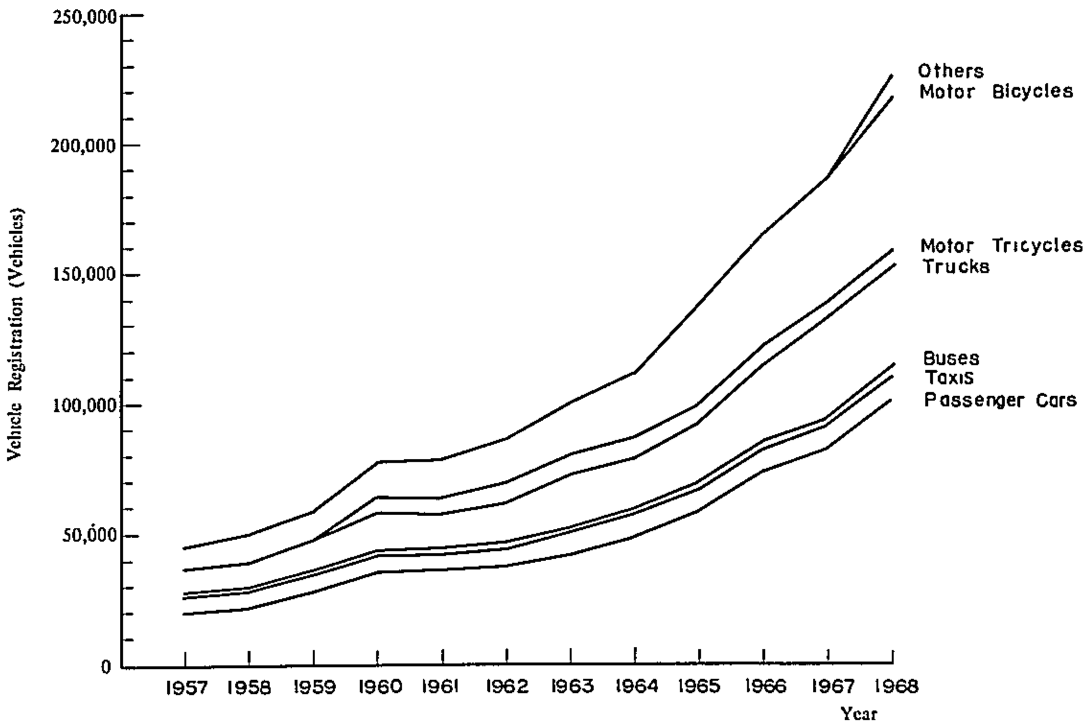
(METROPOLITAN AREA)

Table 2-2-3 Zoning

Zone No. in Area covered for Estimation	Changwat	Amphoe	Tambol
1	Phra Nakhon	Phra Nakhon	–
2		Pom Prap	–
3		Samphanthawong	–
4		The part to the west of Sanam Ma Rd in Pathum Wan	Rong Muang, Wang Mai and a part of Pathum Wan
5		The part to the east of Sanam Ma Rd. in Pathum Wan	Suanlumpini and a part of Pathum Wan
6		Bang Rak	–
7E		The parts to the east and south of Soi Suan Phlu Rd., Nang Linchi Rd., Chan Rd. and Sathu Pradit Rd. in Yan Nawa	Tung Mahamek, Chongnonsi and a part of Bang Pongpang
7W		The parts to the west and north of Soi Suan Phlu Rd., Nang Linchi Rd., Chan Rd. and Sathu Pradit Rd. in Yan Nawa	Yan Nawa, Wat Prayakrai, Bon Korlum, Tung Watdorn and a part of Bong Pong-pang
8		A part of Phra Khanong	Khlong Toey, Khlong Ton and Phra Khanong
9		The part to the east of Northern Rail-way in Dusit	Tanon Petchburi, Tung Payathai, Tanon Payathai, Maggason and a part of Sam-sen Nai
10		The part to the west of Northern Railway and to the south of Khlong Bang Su in Dusit	Wachira Payaban, Dusit, Suan Chitlada, Tanon Nakhonchaisri and a part of Sam-sen Nai
11		The part to the north of Khlong Bang Su in Dusit	Bang Su and a part of Samsen Nai
12		A part of Bang Khen	Lad Yao
13		A part of Bang Kapi	Samsen Nork, Wang Tong Lang, Khlong Chang and Hua Mark
14N		A part of Khlong Sarn	Samdaj Chao Phraya, Khlong Sarn and Khlong Tonsai
14S		A part of Khlong Sarn	Bang Lumpoo Lang
15		Thon Buri	–
16		Bangkok Yai	–
17S		The part to the south of Khlong Bang-kok Noi in Bangkok Noi	Sirjraj, Bang Chang Lor, Bang Kunsri and Bang Kunnon
17N		The part to the north of Khlong Bang-kok Noi in Bangkok Noi	Bang Yikan, Bang Suanra, Bang Plad and Bang Or

Zone No. outside of Area covered for Estimation	Changwat
18	The rest of Phra Naknon
19	The rest of Thon Buri
20	Nontha Buri
21	Nong Khai, Udon Thani, Sakon Nakhon, Nakhon Phanom, Chaiyaphum, Khon Kaen, Kalasin Nakhon Ratchasima, Maha Sarakham, Roi Et, Ubon Ratchathani, Buri Ram, Surin, Si Sa Ket
22	Samut Prakan, Chachoengsao, Prachin Buri, Chon Buri, Rayong, Chanthaburi, Trat
23	Kanchanaburi, Ratchaburi, Nakhon Pathom, Samut Sakhon, Samut Songkhram, Phetchaburi, Prachuap Khiri Khan, Chumphon, Ranong, Surat Thani, Phang-Nga, Phuket, Krabi Nakhon Si Thammarat, Trang, Phatthalung, Narathiwat, Yala, Pattani, Satun, Songkhla
24	Pathum Thani, Nakhon Nayok, Suphan Buri, Saraburi, Ang Thong, Lop Buri, Sing Buri, Chai Nat, Phrae, U.Thai Thani, Tak Kamphaeng Phet, Phichit, Phetchabun, Nakhon Sawan, Sukhothai, Phitsanulok, Loei, Mae Hong Son, Chiang Mai, Lamphum, Lampang, Chiang Rai, Nan, Uttaradit, Phra Nokhon Si Ayutthaya

Fig. 2–2–4 ANNUAL VEHICLE REGISTRATION



c) Traffic Volume

Fig. 2-2-5 which shows the results of the traffic counts reveals the concentration of traffic in the central business district. The Memorial Br. and its connecting roads are badly congested carrying especially heavy traffic. The daily traffic on it exceeds 100,000 vehicles. This bridge built in 1932 has insufficient width and is deteriorated so much that the vehicles with ten or more wheels or over fifteen tons in gross weight are prohibited to pass.

Charoeng Krung Rd. is characterized by its many factories and stores along it, and so it carries a great volume of traffic of large trucks with many vehicles parking on its road side; all this intensifies the congestion on the road which didn't have a sufficient capacity from the outset.

d) Problems of Road Traffic

As the reasons for the considerable congestion of traffic now on the roads, which are the main constituent of the transport system in the Metropolitan Area, the following may be said:

i) That the improvement and expansion of the street network have not caught up with the rapid increase in the volume of road traffic resulting from the sudden advance of motorization in recent years.

ii) That the scarcity of bridges across the Mae Nam Chao Phraya make it difficult to form ring roads.

iii) That the insufficient parking facilities in the central business district have the effect of increasing roadside parking which in turn reduces the capacity of the streets.

iv) That some of the street intersections, almost all of which are the rotary type at grade, have reached their capacities to meet the traffic demand. Adequate measures must be taken without delay to solve these problems.

(4) Traffic across the Mae Nam Chao Phraya

a) Vehicular Traffic

At present, the chief means of transportation between Bangkok and Thon Buri separated by the Mae Nam Chao Phraya are motor vehicles and ferryboats. First, the vehicle traffic is considered in this paragraph.

The vehicles use four bridges linking these two cities, that is the Rama 6 Br., the Krung Thon Br., the Memorial Br. and the Krung Thep Br., as mentioned before, from the upper stream side of the Mae Nam Chao Phraya.

According to Fig. 2-2-6 which shows the results of the traffic counts carried out on the above four bridges, the traffic volume between Bangkok and Thon Buri amounts to 126,000 vehicles for the 12-hours period in the daytime. The Memorial Br. accounts for about 60% of them, or 74,000 vehicles, and this bespeaks the importance of the bridge which connects the central business district of Bangkok directly with that of Thon Buri.

On the other hand, the Rama 6 Br. is situated at the edge of the city and the traffic volume on it accounts for only 5%, or 6,500 vehicles. Therefore, it may be concluded that the traffic volume between Bangkok and Thon Buri is carried by three bridges, that is the Memorial Br., the Krung Thon Br. and the Krung Thep Br. in the order of their traffic roads.

In regards to the type of the traffic between Bangkok and Thon Buri, Fig. 2-2-6 shows that the passenger cars account for the largest percentage, or 40% and the motorcycles and taxis come next with a little less than 20%. It is clear that the motorcycles play an role not to be ignored as the means of transportation at present.

Remarkable differences are seen in the percentages of trucks betwen each of the four bridges. The Memorial Br. accounts for only 7% and this is due to the fact that the bridge forms the connecting route between the two central business districts and the large trucks are prohibited from passing over it. To the contrary, the Krung Thep Br. has the largest ratio of trucks compared with other bridges, coming near to 30%. It may be because of factories and warehouses concentrating along Charoen Krung Rd. leading to the Bridge.

The origin and destination of the traffic between Bangkok and Thon Buri are shown on the basis of the OD study in Fig. 2-2-7 in relation to the city areas and in Fig. 2-2-8 as the desire lines between the two cities.

Fig. 2-2-7 shows that, of the 12-hour traffic volume across the Mae Nam Chao Phraya, that is 94,000 vehicles, the through traffic not originating or destinating in the city of Bangkok or Thon Buri counts for only about 1,100 vehicles or a little over 1%. Almost all of the traffic across the four bridges are related to the Bangkok and Thon Buri Cities. This can be understood from the fact that the Bangkok and Thon Buri are the centers of Thailand in every respect; politics, industry, culture, etc.

The traffic flowing in and out of the cities of Bangkok and Thon Buri amounts to 20,000 vehicles representing one fifth of the total volume. As is found in Fig. 2-2-8, the only zone pair having more than 2,000 vehicles is that of Zone 1 (Amp. Phra Nakhon) and Zone 19 (Cha. Thon Buri other than the Thon Buri City).

The traffic between Zone 17 (Amp. Bangkok Noi) and Zone 20 (Cha. Nontha Buri) mainly using the Rama 6 Br. accounts for about 1,200 vehicles, or accounts for a little less than 20% of the 6,500 traffic volume on that bridge shown in Fig. 2-2-6. Therefore, it seems that the traffic between Bangkok and Thon Buri as well as Thon Buri and Suburbs of Bangkok of these cities, takes a considerable proportion of the traffic volume on the Rama 6 Br. The traffic between the cities of Bangkok and Thon Buri accounts for about three quarters of the traffic volume on the four bridges.

The details of traffic volume by zone pairs are shown in Fig. 2-2-8. It is a matter of course that the traffic volume between Zone 1 and Zone 15 (Amp. Thon Buri) takes the largest volume of about 8,000 vehicles; because these two zones respectively from the central business districts of Bangkok and Thon Buri. The pair having the second largest volume of traffic between zones is that of Zone 1 and Zone 17; the latter has a large area (23.0 km^2) with the commercial district around the Thon Buri Station. Other zone-pairs having a traffic volume of over 3,000 vehicles include zone-pairs 10-17, 3-15, 7-15, and 9-15.

b) Ferry

The transport by water plays an important role as a means of transportation on the plains of Thailand, in some cases constituting the only means of transport.

Although many Khlongs running through the city are used as waterways, the transport by water does not have so much importance in the cities of Bangkok and Thon Buri. Boats crossing the Mae Nam Chao Phraya from Bangkok to Thon Buri, or vice versa, are used to going on Khlongs branching off the river. This practice seems apparent particularly in the case of goods transportation.

The ferries used by the public can accommodate from twenty to scores of passengers and are playing regularly between the banks of the Mae Nam Chao Phraya. There are 22 ferry stations to and from where such ferreis operate on the river banks extending aobut 16.7 km from the Rama 6 Br. to the Krung Thep Br., at a rate of one station per 760m, as shown in Fig. 2-2-9.

The results of the weekly survey carried out by the Harbor Department are compiled in Fig. 2-2-9 which shows that the passengers using the ferry service amount to an average of 160,000 persons per day. If so many passengers are to be transported by road it will need 5,300 buses on the assumption of carrying thirty passengers per bus, which corresponds to 55% of 9,600 buses shown in Fig. 2-2-6 operating between Bangkok and Thon Buri.

These figures will convince one of the importance of a ferry as a means of transportation between Bangkok and Thon Buri. Besides such ferries plying between the fixed stations like the bus service, some number of taxi-like ferries operate departing from and arriving at any station and a considerable number of passenger are estimated to be carried by them. Fig. 2-2-9 shows that six ferry stations of Tevesa, Prachan Nue (Prenok), Prachan Khlong (Middle), Tha Chang, Rajavong and Si Praya average more than 10,000 passengers in daily. At these stations, the ferries operate at intervals of as short as 2-3 minutes during the peak hours in the morning and evening.

The result of interviews carried out to know which means of land transportation are used by the ferry passengers is shown in Fig. 2-2-10. The passengers using buses or samlors at both ends on the Bangkok and Thon Buri sides who may be regarded to be travelling a comparatively long distance amount to 3,800 persons or account for as much as 90% of the ferry passengers interviewed. While the passengers who use buses or samlors at either

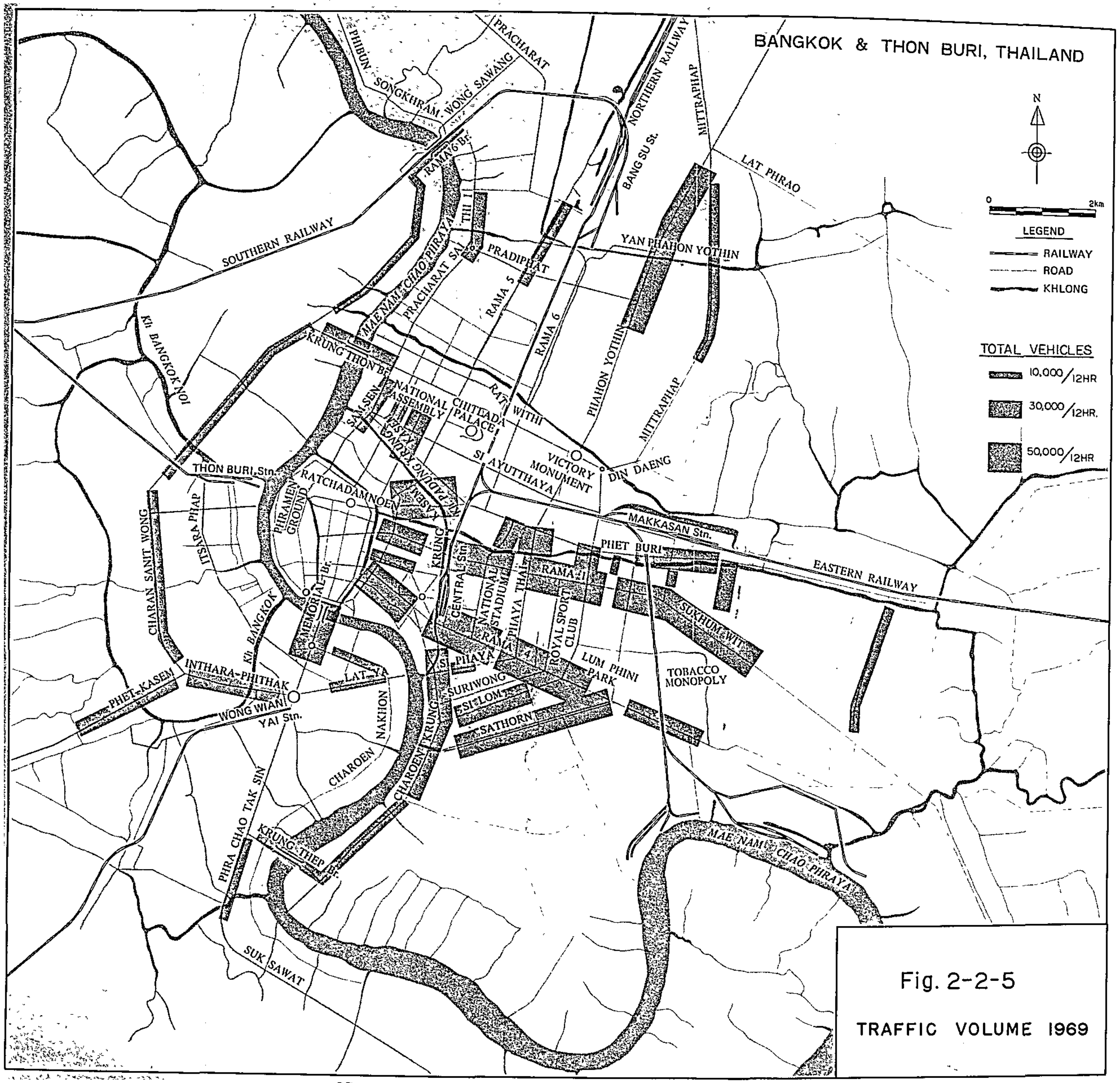


Fig. 2-2-5

TRAFFIC VOLUME 1969

Fig. 2–2–6 TRAFFIC VOLUME ON THE FOUR BRIDGES BETWEEN BANGKOK AND THON BURI 1969

Unit : vehicles/12 hours Figures in parentheses show percentages

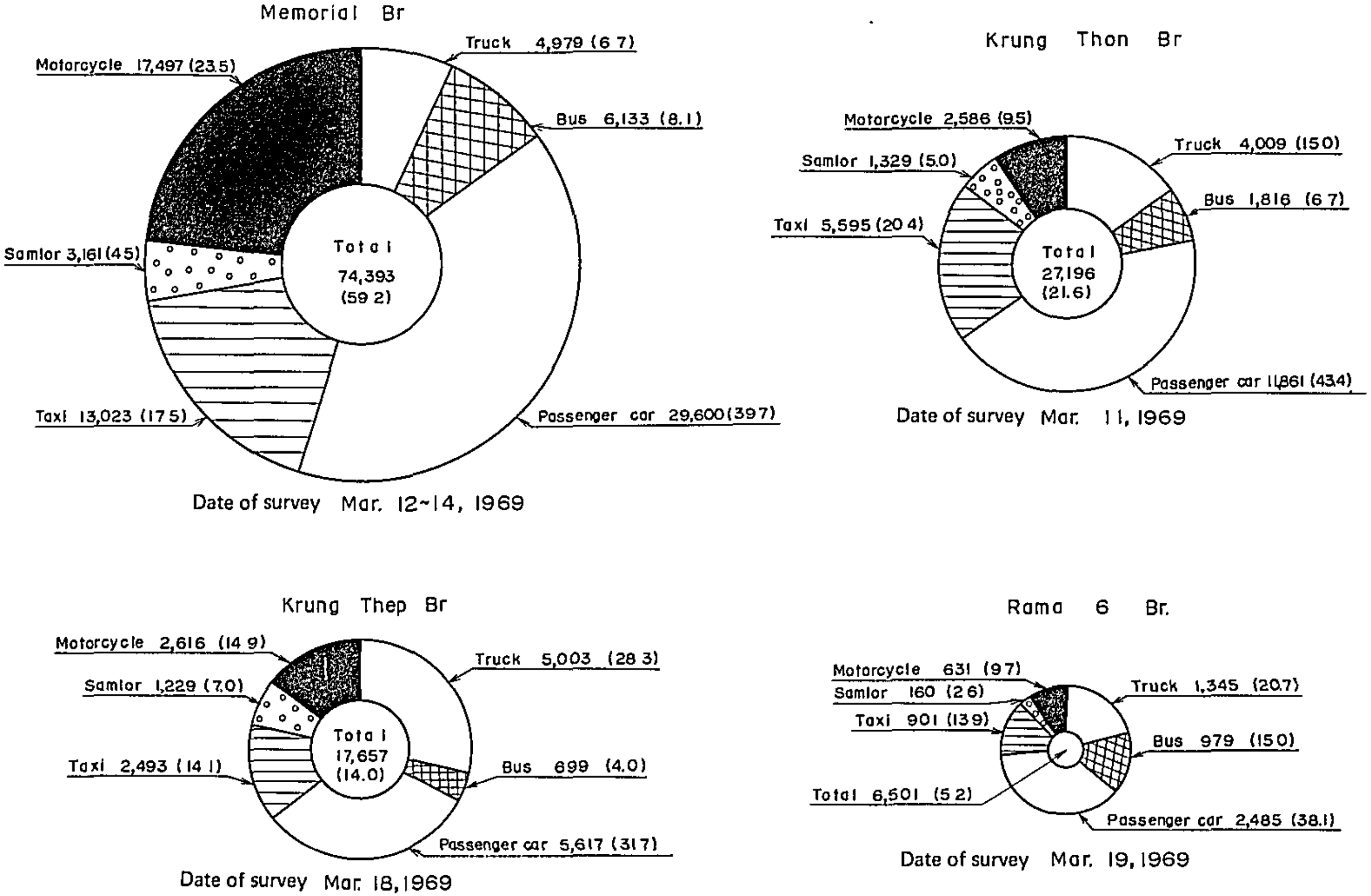


Fig. 2-2-7 ORIGIN AND DESTINATION OF THE TRAFFIC ACROSS THE MAE NAM CHAO PHRAYA

Unit : vehicles Figures in paretheses show percentages

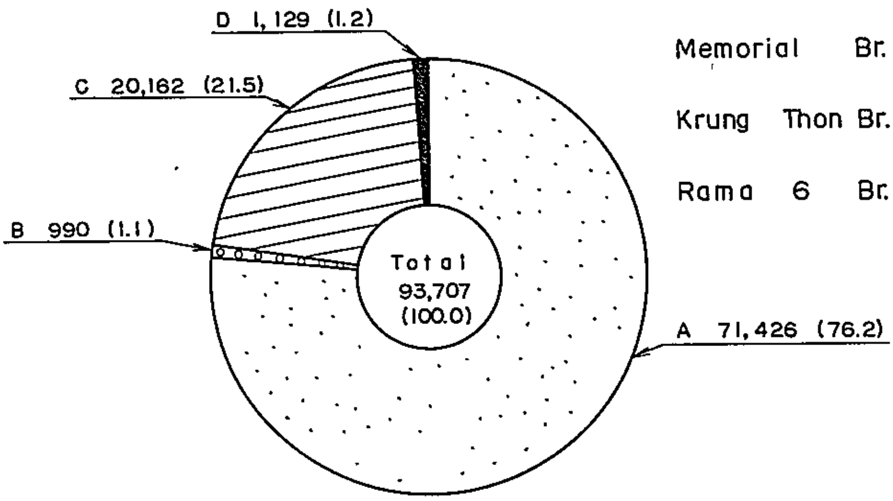
Date of survey

Krung Thep Br. Mar. 18, 1969

Memorial Br. Mar. 12~14, 1969

Krung Thon Br. Mar. 11, 1969

Rama 6 Br. Mar. 19, 1969



A — Traffic between Bangkok and Thon Buri

B — Traffic within either Bangkok or Thon Buri

C — Traffic flowing in or out of either Bangkok or Thon Buri

D — Traffic passing through Bangkok and Thon Buri

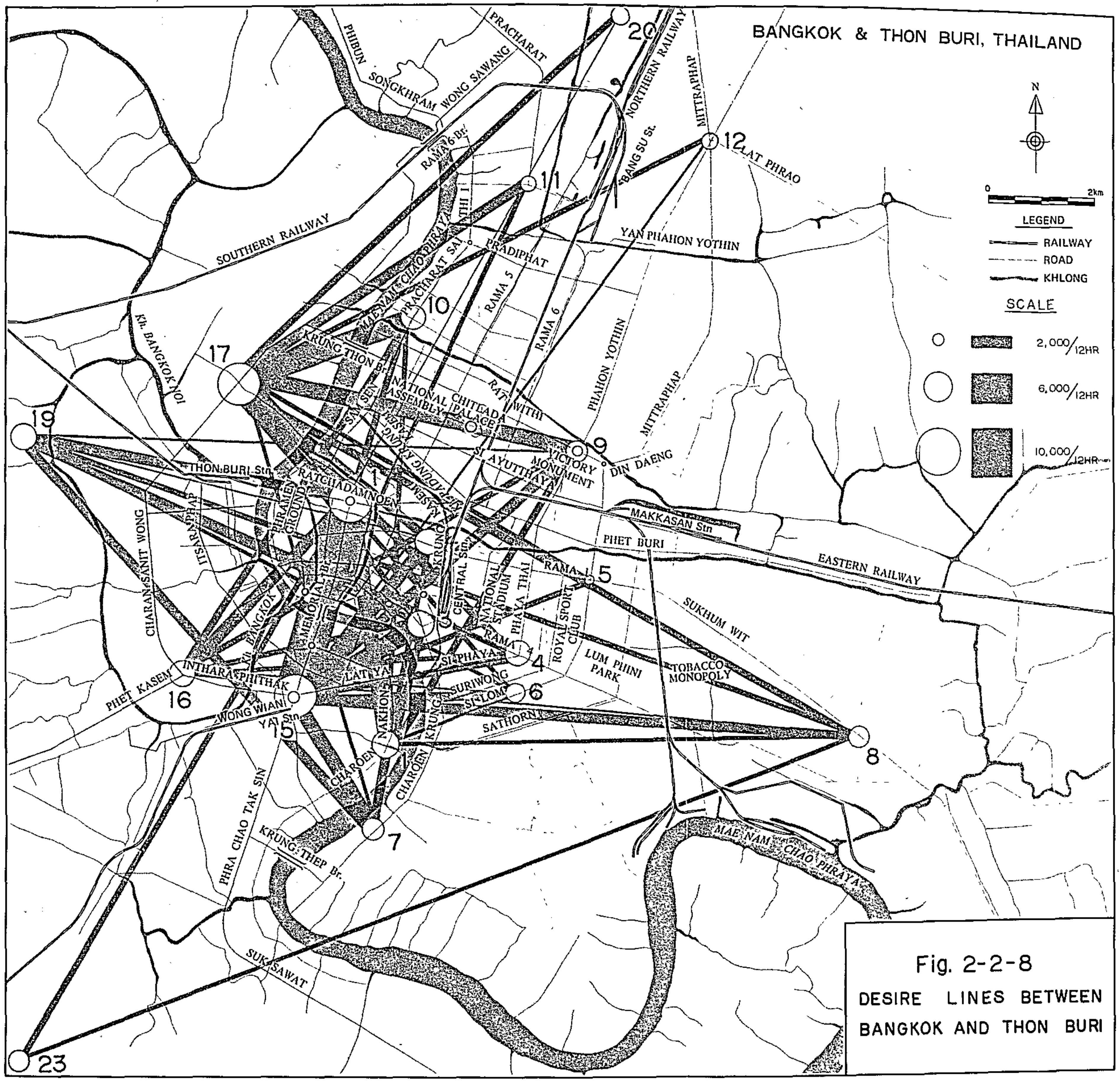


Fig. 2-2-8

DESIRE LINES BETWEEN BANGKOK AND THON BURI

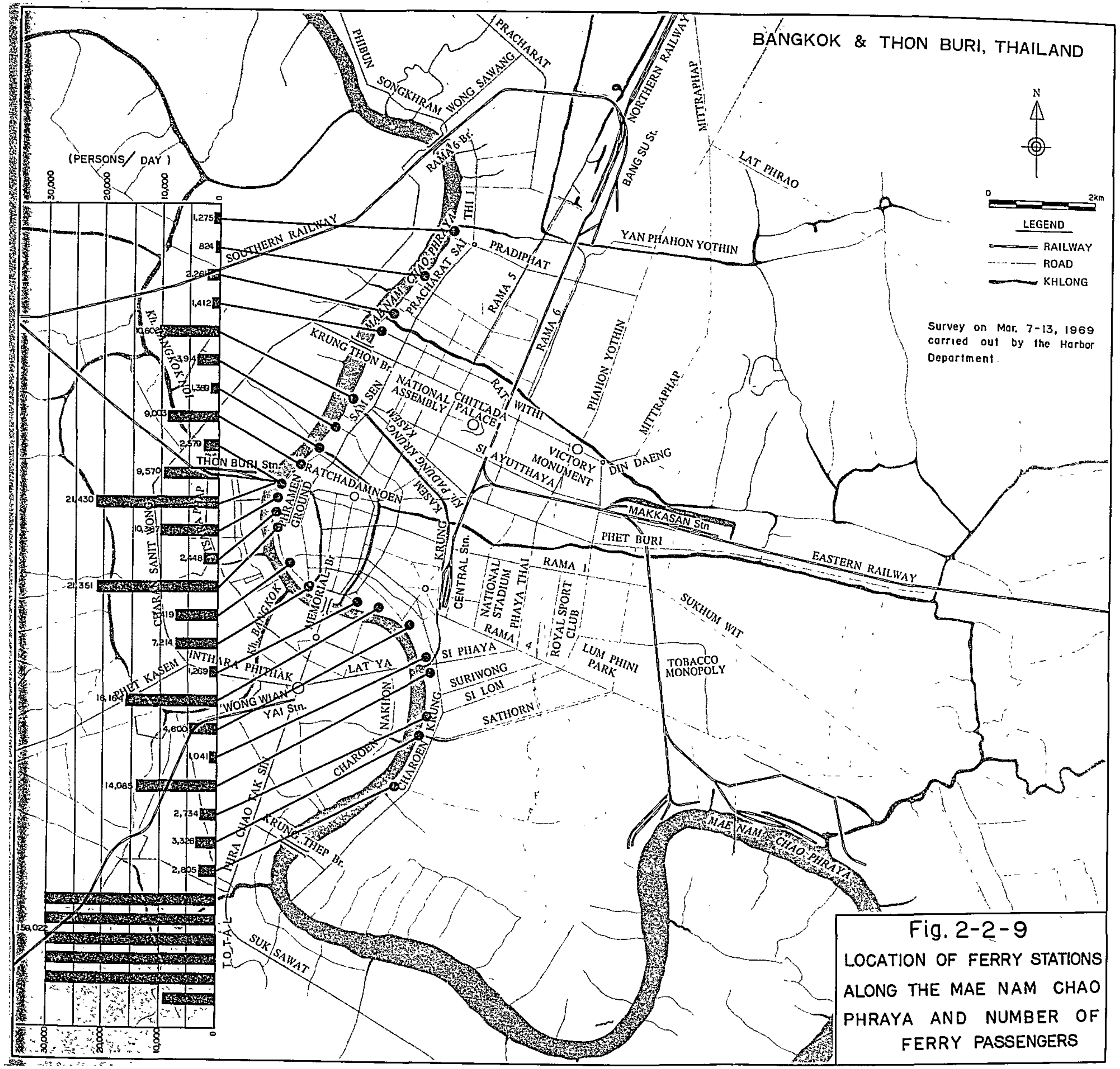
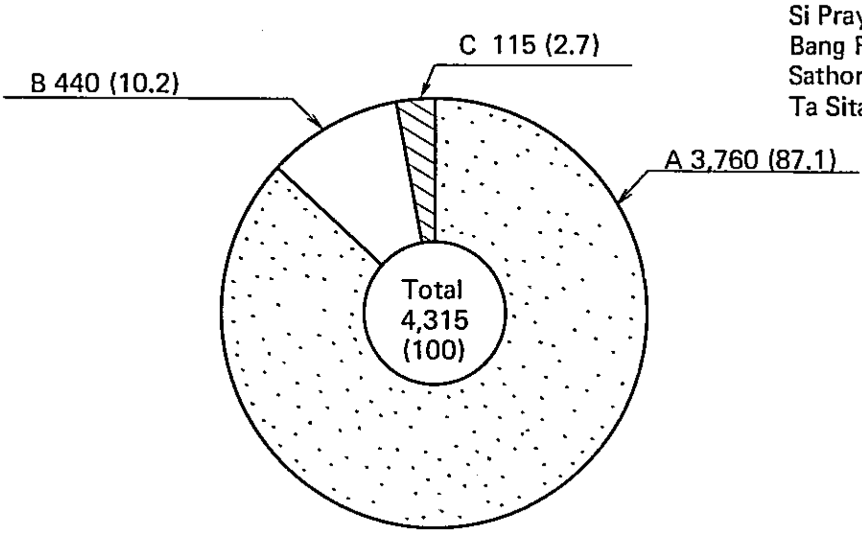


Fig. 2-2-9
LOCATION OF FERRY STATIONS ALONG THE MAE NAM CHAO PHRAYA AND NUMBER OF FERRY PASSENGERS

Fig. 2—2—10 LAND TRANSPORTATION OF FERRY PASSENGERS

Unit : persons
Figures in parentheses show percentages

Date of survey : Apr. 1, 1969
Location of survey :
Rajavong
Swasdi
Si Praya
Bang Rak
Sathorn Tai
Ta Sita



Note:

A — Passengers who use buses or samlors at both ends on the Bangkok and Thon Buri sides

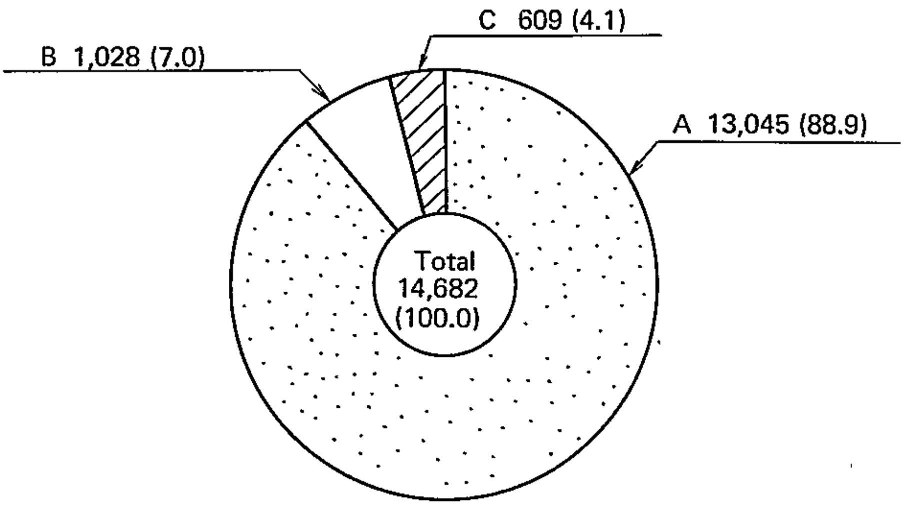
B — Passengers who use buses or samlors at one end on the Bangkok or Thon Buri side

C — Passengers who travel on foot on both the Bangkok and Thon Buri side

Fig. 2–2–11 ORIGIN AND DESTINATION OF THE TRAFFIC THROUGH THE MEMORIAL BRIDGE

Unit : vehicles
Figures in paretheses show percentages

Date of survey : Mar. 12 ~ 14, 1969



A – Traffic originating and destinating at the central business districts of Bangkok and Thon Buri

B – (1) Traffic passing through Bangkok and Thon Buri

(2) Traffic flowing in and out of the outlying areas of Bangkok and Thon Buri

C – Traffic across the Mae Nam Chao Phraya, but confined in Bangkok end number 440 persons, or 10%, those who are travelling a short distance on foot at both ends number only a little more than 100 persons, or 3%.

Accordingly, the ferry is a means of transportation which people are compelled to use in the absence of convenient land transportation for crossing the river. If the bridge is constructed, a substantial part of the ferry passengers is naturally anticipated to convert to bus users. This can be a potential demand for the transport by bus.

c) Traffic on the Memorial Bridge

The Memorial Br. connects with the central business districts of Bangkok and Thon Buri and forms a part of the most important street network in the Metropolitan Area. Nevertheless, the capacity of the Memorial Br. is substantially insufficient to meet the traffic demand resulting in traffic stagnation all the time.

On the one hand, the roads in the area around the Memorial Br. on the Bangkok side do not have sufficient capacity. As the Memorial Br. is the bottle neck of the traffic flowing from the Thon Buri side, it seems the roads on the Bangkok side are released from being directly stagnated. If it is planned, in the future, to increase the width of the Memorial Br. or to construct a new bridge near to it and adequate consideration should be given to the capacity of its connecting roads.

The traffic on the Memorial Br. is not necessarily confined to that between the central business districts of the two cities. This issue is to be considered referring to Fig. 2-2-11 which has been prepared by rearranging the results of the OD survey.

Out of about 15,000 vehicles surveyed at the Memorial Br., 1,000 vehicles, or 7%, are those passing through Bangkok and Thon Buri and those originating or destinating the district outside of Thon Buri or the outskirts of Bangkok. These types of traffic will never need to pass through the central business district if the road network is properly improved around the two cities.

Although some 600 vehicles, or 4%, travel between two points within Bangkok, they move once to the Thon Buri side and return to the Bangkok side. In fact, there are a few cases where this practice reduces the travelling distance, but it seems such a course is selected to reduce the travel time. The reason is that, in particular on such roads leading to the central business district along the Mae Nam Chao Phraya in Bangkok as the Charoen Krung Rd., etc., the traffic is severely stagnated resulting in an extremely low travelling speed.

It may be expected to reduce the traffic congestion on the Memorial Br. by about 10% by building ring roads around Bangkok and Thon Buri and radial roads (Charoen Krung Rd. and Rama 4 Rd., for example) leading to the central business district of Bangkok. Since the Memorial Br. is a part of the street network in the integrated metropolitan area of Bangkok and Thon Buri, the traffic volume on it should be reviewed in reference to the metropolitan raod network.

2-3 Future Traffic in the Metropolitan Area

The traffic across the Mae Nam Chao Phraya suggest the pressing need to construct the Sathorn Br. However, considering that preparations are being made to start the construction work on the Tha Chang Br., the possibility seems to be slight for the Sathorn Br. being open for traffic before 1975. Hence 1975, when the bridge is to open for traffic, is selected as the year for estimating the future volume of traffic. As for the growth thereafter, such estimation of traffic volume will be made in 1990. Reference is made to the separate report, as to the details of the traffic study.

(1) Compilation of the Present complete OD Table

The OD table which is prepared from the roadside interviews indicates the origins and destinations of the traffic only between Bangkok and Thon Buri and not those of all traffic in the city areas. It is proper to begin with deducing a complete OD table for the city area from the incomplete OD table of the traffic between Bangkok and Thon Buri. It is done by the following method.

First, assuming that gravity models are applicable to the traffic generation in this area, the traffic generation in each zone and the exponents of travel times between the zones in gravity models are found, based on the incomplete OD table and the assumed travelling time between the zones in Bangkok and those in Thon Buri.

Next, complete OD tables are computed from the traffic generation and the exponents thus found, by means of the entropy method advocated by Prof. T. Sasaki of Kyoto University.

Then, the complete OD table is checked in the following two ways. The traffic volume obtained from the computed complete OD table on each of several screen lines is compared with that obtained by manual count. Also the computed zone-pair trips crossing the Mae Nam Chao Phraya are compared with those obtained from the OD survey.

After several trials, the computed desire lines shown in Fig. 2-3-1 are obtained and this is regarded as a reasonable result.

(2) Estimation of Future Traffic

Then the future traffic volume is estimated by the following produce based upon the deduced OD table.

First, the future number of registered vehicles is estimated and is multiplied by the present daily trips per vehicle to compute the total number of daily trips in the future in the area covered for estimation.

Next, the relation between the present traffic generation by zones and the present land use by zones is expressed in the form of regression function, in which the present land use is replaced with the future land use to estimate the future traffic generation by zones.

On the basis of the total number of daily trips and traffic generation by zones, the future OD distribution was computed by means of the entropy method.

Finally, this OD traffic volume is assigned to the future road network to obtain the future traffic volume by sections of roads.

The number of registered vehicles, the traffic generation by zones and the volume of distributed traffic are estimated respectively by passenger cars, taxis, and trucks. Salmors are included in taxis, and motorcycles are excluded from the estimation as its importance will decrease in the future.

a) Growth of Vehicle Registration

This paragraph considers the variation in vehicle registration which is the basis for estimating the future traffic volume.

The growth rates of vehicle registration and accordingly the factors governing them differ with the types of vehicles. The vehicles are classified into passenger cars, taxis and trucks, and analysis is made by correlating registered vehicles throughout Thailand with such

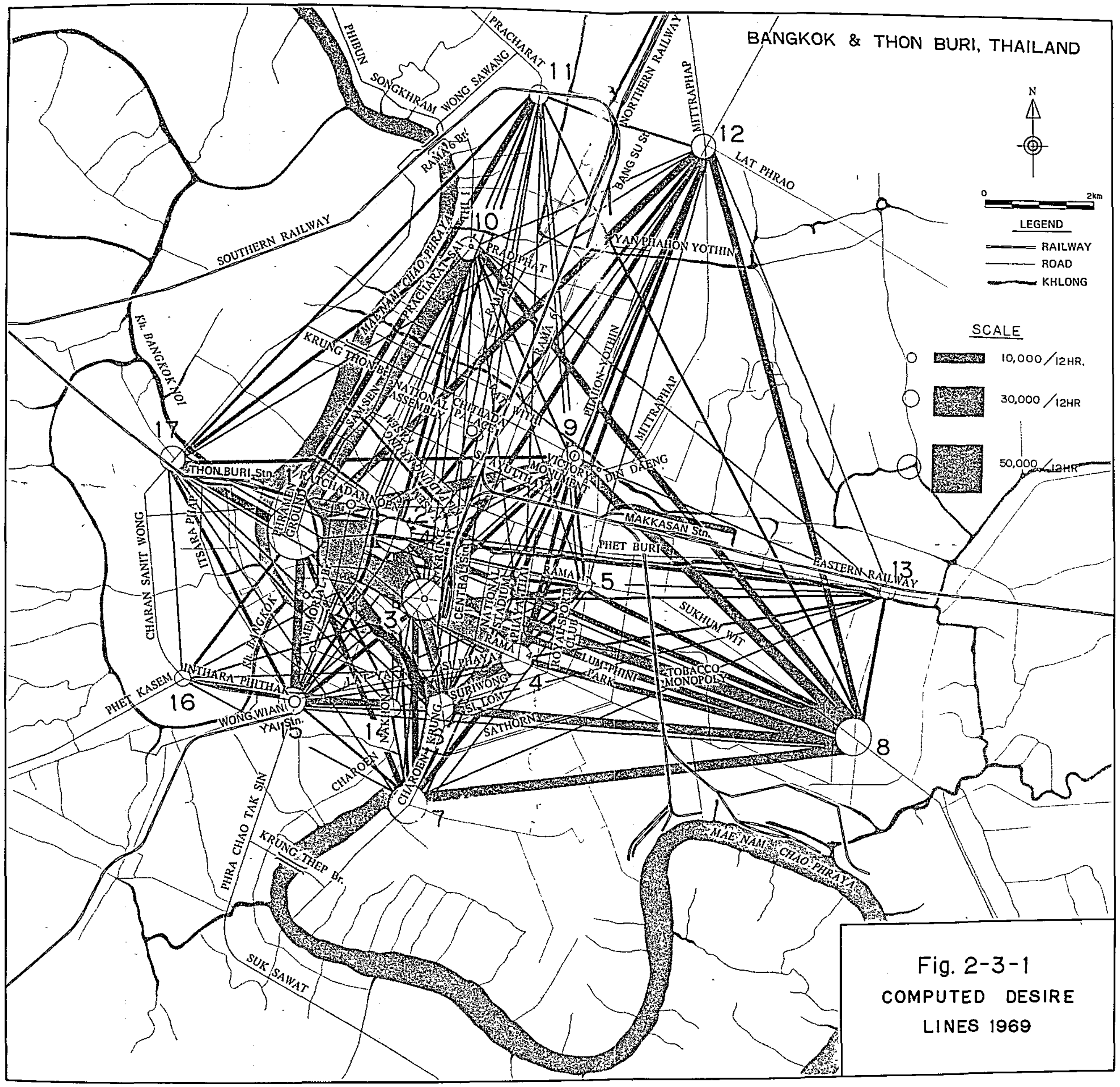


Fig. 2-3-1
COMPUTED DESIRE
LINES 1969

economic indicators as population, gross national product (GNP), consumers' expenditure and capital formation. Eventually, it is found that Figs. 2-3-2 through 2-3-4 show reasonables and simple relations between different types of vehicles and economic indicators.

In Figs. 2-3-2 through 2-3-4, the number of passenger cars is worked out based on the population, and those of taxis and trucks respectively based on the consumers' expenditure and GNP.

As of 1968, the total number of vehicles of all types in Bangkok and Thon Buri was 157,000 vehicles made up of 103,000 passenger cars taking the largest number, 39,000 trucks and 16,000 taxis. Figs. 2-3-2 through 2-3-4 show that these numbers in 1975 are expected to be 159,000 passenger cars, 73,000 trucks and 37,000 taxis, and those in 1990 to be respectively 288,000, 228,000 and 99,000 vehicles totaling 615,000 vehicles. Putting it in another way, the passenger cars will increase 1.6 times, the trucks 1.9 times and the taxis 2.4 times, or 1.7 times on an average, in the seven years from 1968 to 1975. Also, each type of vehicle will increase respectively 1.8, 3.1 and 2.7 times, or 2.3 times on an average, in the fifteen years from 1975 to 1990.

The reason for the low growth rate of passenger cars is that the structure of vehicle ownership now in Thailand is made up of the passenger cars as its nucleus, with the passenger cars accounting for about 65% of all vehicles. A remarkable increase of trucks is seen especially from 1975 onward, but this seems reasonable considering that the traffic demands having now recourse to water transportation are expected to transfer to road transportation with the high advancement of the industrial structure of Thailand in the future.

These registered vehicles by their types, (projected in the future) were multiplied by respective average trips per vehicle (3.94 for passenger cars, 31.12 for taxis and 4.18 for trucks),

Fig. 2–3–2 REGISTERED PASSENGER CARS AND POPULATION

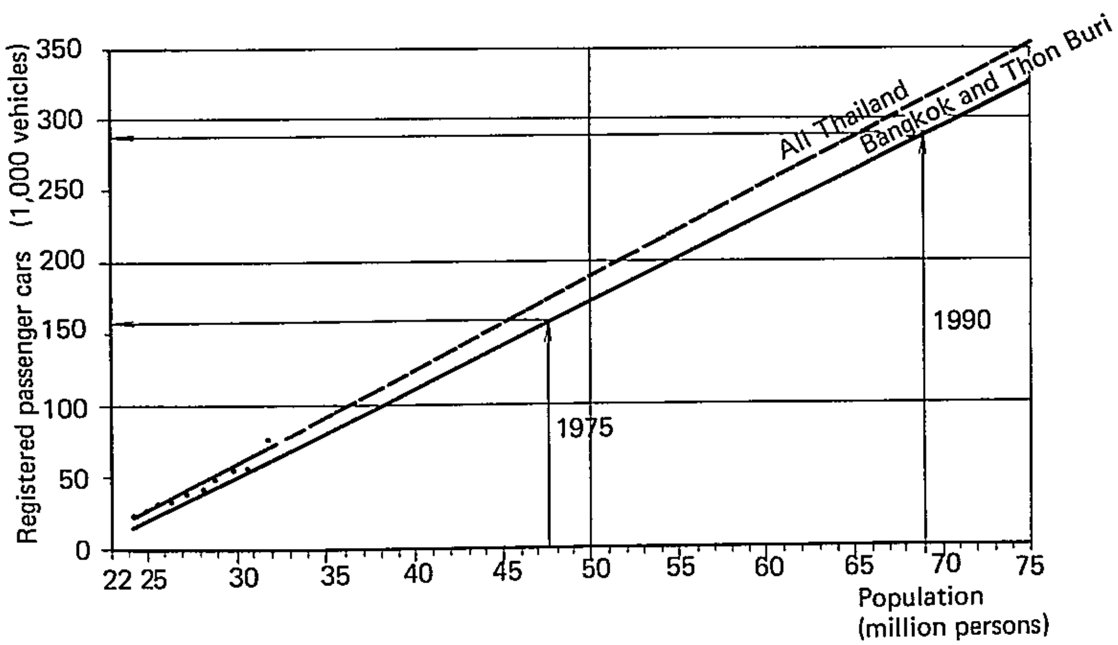


Fig. 2–3–3 REGISTERED TAXIS AND CONSUMERS' EXPENDITURE

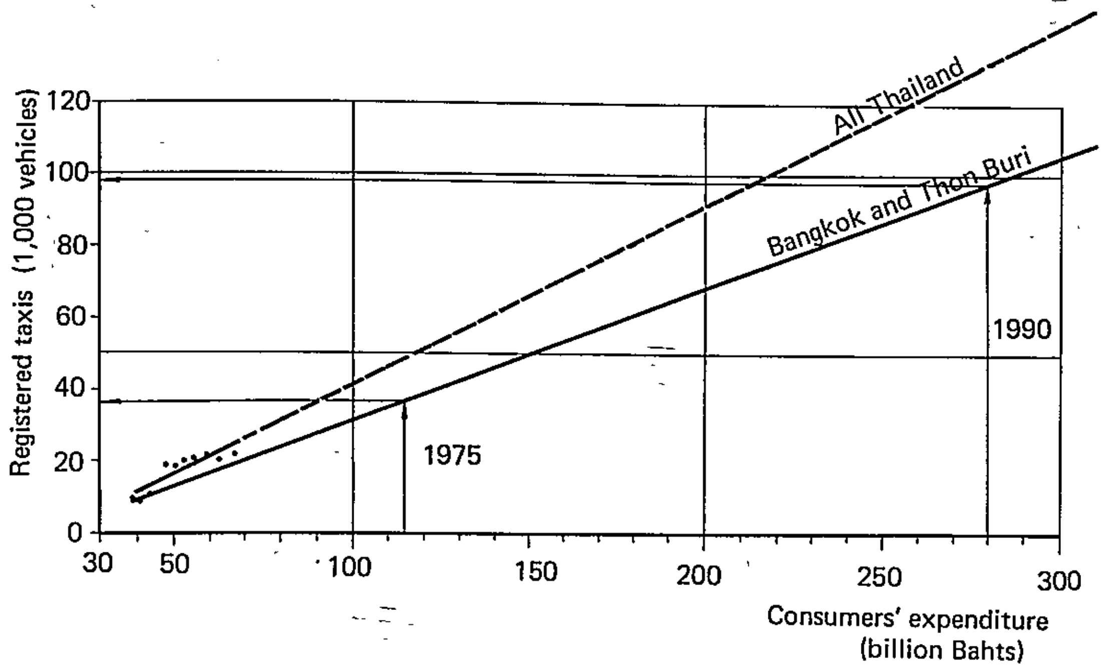
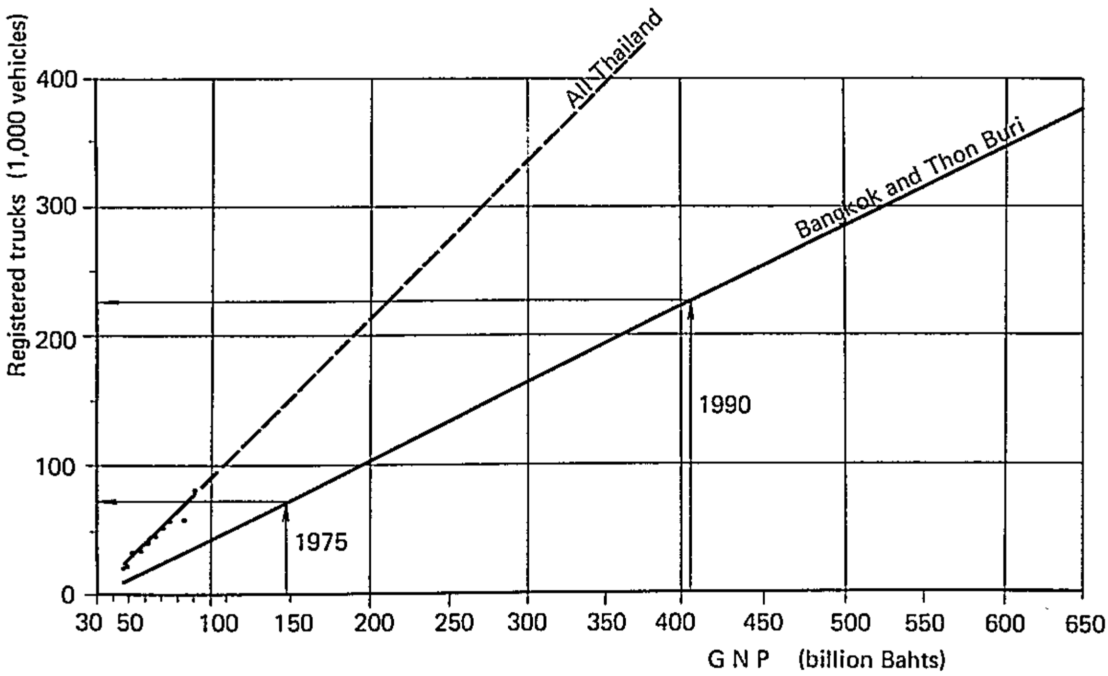


Fig. 2–3–4 REGISTERED TRUCKS AND GNP



as worked out in the preceding paragraph, to compute the total vehicle trips in Bangkok and Thon Buri in the future. The total for 1975 is 2,080,000 trips and that for 1990 5,160,000 trips; these are respectively as much as 2.0 times and 4.9 times of 1,050,000 trips for 1969.

b) Future Traffic Generation.

The traffic generation by zones must be determined at first to find the OD distribution.

In this report, the traffic generation is computed in relation to the land use.

On the basis of the correlation between the present traffic generation and the areas with different land use in the zones, obtained from the aforesaid land use map, the residential districts, commercial districts and governmental owned land (except parks) are adopted as the independent variables of the regression function for generated traffic of passenger cars; the residential districts, commercial districts, government owned land and land for utilities are adopted as those of taxis; and the commercial districts, industrial districts and government owned land are adopted as those of trucks.

The City Planning Division of the Bangkok City has planned the land use for the year 2000 as shown in Fig. 2-3-5.

The areas by districts of different land usage in each zone are computed for 1975 and 1990 assuming that they will change uniformly with the lapse of time from the present status to that shown on this Figure. These areas are applied to the above regression function for generated traffic to determine the traffic generations in 1975 and 1990.

This traffic generation is used as a relative weight by zones and the total trips as computed in the preceding paragraph are used as a control total, that is as the total traffic generation of all zones. Accordingly, the traffic generation of a zone is found as the product of the total trips and the relative weight of that zone.

The following trends are revealed by the examination of Fig. 2-3-6 which shows the estimated growth of traffic generation by zones.

Zones 1, 2, 3 and 4 (Amp. Phra Nakhon, Pom Prap, Samphanthawong and western half of Pathum Wan) have the lowest growth rates, with traffic generation in 1990 having increased to the extent of 1.8-2.6 times of that in 1969. It is just half the average growth rate, or 4.9 times the total trips in all zones. It is because these zones are central business districts in which the urban functions have already concentrated and do not have so much room for further development.

On the other hand, those having especially high growth rates more than nine times (about twice the average growth) include Zone 7 (Amp. Yan Nawa), Zone 8 (Amp. Phra Khanong), Zone 9 (the eastern part of Amp. Dusit), Zone 15 (Amp. Thon Buri) and Zone 17 (Amp. Bangkok Noi). These zones are now situated in the outlying area and the future development plan directed toward the city environs is reflected in the growth of traffic generation in them. As seen clearly on the future land use map, the growth in the first two zones is due to the plan for developing the land along the Mae Nam Chao Phraya in the southern and southeastern parts of Bangkok City. The last three zones are on the Thon Buri side which has only one more zone, Zone 16 (Amp. Bangkok Yai), and it is clear that Thon Buri City is developing more rapidly than Bangkok City.

Those having the average growth rate of traffic generation are Zone 5 (the eastern half of Amp. Pathum Wan), Zone 10 (the western part of Amp. Dusit), Zone 11 (the norhtern part of Amp. Dusit), Zone 13 (Amp. Bang Kapi) and Zone 16 (Amp. Bangkok Yai).

Fig. 2–3–5

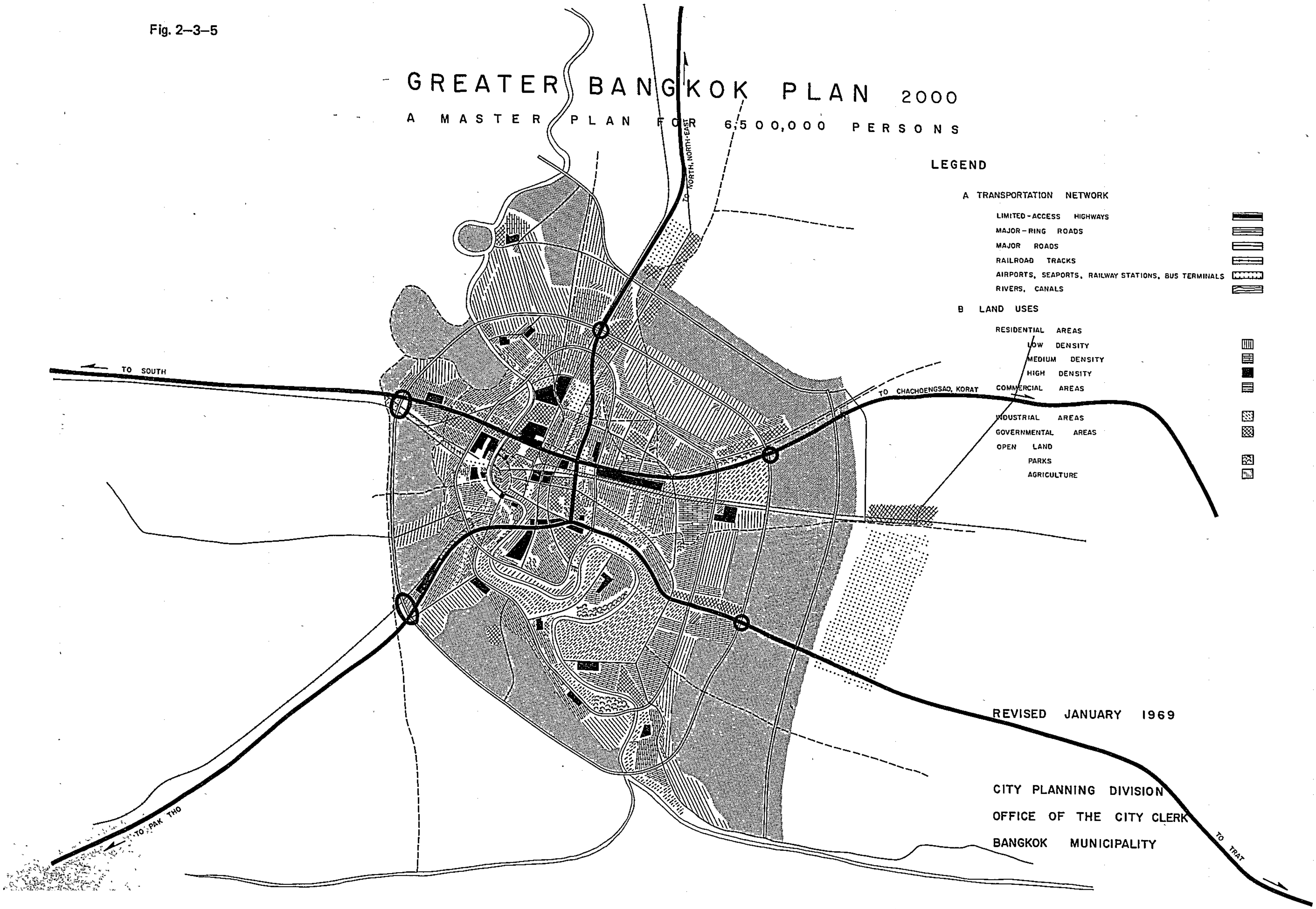
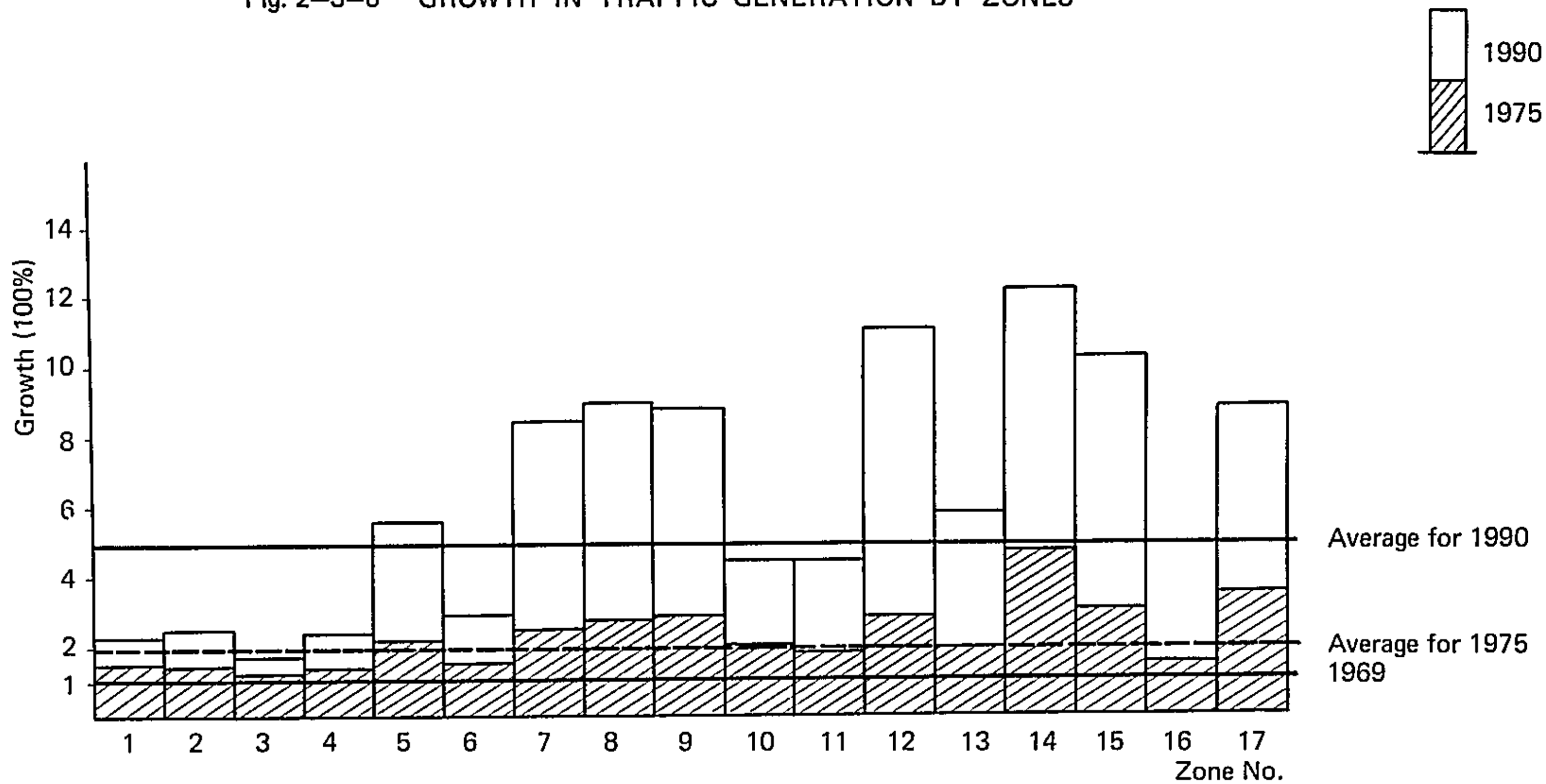

GREATER BANGKOK PLAN 2000
A MASTER PLAN FOR 6,500,000 PERSONS
LEGEND
A TRANSPORTATION NETWORK
LIMITED-ACCESS HIGHWAYS
MAJOR-RING ROADS
MAJOR ROADS
RAILROAD TRACKS
AIRPORTS, SEAPORTS, RAILWAY STATIONS, BUS TERMINALS
RIVERS, CANALS
B LAND USES
RESIDENTIAL AREAS
LOW DENSITY
MEDIUM DENSITY
HIGH DENSITY
COMMERCIAL AREAS
INDUSTRIAL AREAS
GOVERNMENTAL AREAS
OPEN LAND
PARKS
AGRICULTURE
TO NORTH, NORTH-EAST
TO SOUTH
TO CHACHOENGSAO, KORAT
TO PAK THO
TO TRAT
REVISED JANUARY 1969
CITY PLANNING DIVISION
OFFICE OF THE CITY CLERK
BANGKOK MUNICIPALITY

Fig. 2–3–6 GROWTH IN TRAFFIC GENERATION BY ZONES



c) Future Traffic Distribution

The future traffic distribution table can be computed with the traffic generation by zones and the total trips found by the methods described above. The desire lines for 1975 and 1990 compiled from the results of computation are shown respectively in Fig. 2-3-7 and Fig. 2-3-8.

The following changes will be noticed by comparing Figs. 2-3-7 and 2-3-8 with the present desire lines shown in Fig. 2-3-1.

First, the traffic volume between Bangkok and Thon Buri will be 217,000 trips in 1975 and 598,000 trips in 1990, growing respectively 2.8 and 7.8 times the present volume. These values are much greater than the growth rates of the total trips (respectively 2.0 and 4.9 times), due to the accelerated development of Thon Buri as well as the traffic induced by the Tha Chang and Sathorn Brs.

Needless to say, since the traffic volume between Bangkok and Thon Buri accounts for the greater part of the traffic across the Mae Nam Chao Phraya, any construction of a bridge over the river should be planned on the basis of it.

Second, it is noticed that the traffic volume becomes conspicuously great between respective zones in the outlying area. This is a result of the relative importance in traffic generation being moved to the outlying area.

Among other things, the traffic volume respectively between Zones 7W-8 and 8-9 will exceed the level of 100,000 vehicles in 1990. Also the traffic volume in 1990 in zone pairs 1-9, 8-12 and 9-12 will exceed 40,000 vehicles, and those in the zone pairs 1-10, 8-10, 7E-15 and 14N-15 30,000 vehicles. Out of the traffic of these nine zone pairs, only two pairs, 1-9 and 1-10, consist of traffic between the city center and the outlying area, that is the traffic moving in the radiating direction, and all the rest consist of traffic between zones in the outlying area, representing the ring movement. However, Zone 15 is the center of Thon Buri City and seems to have the character of a sub-central business district. Only two pairs are associated with this zone, and but even so a remarkable growth is anticipated in the traffic in the outlying area. It should be noted that the figures displayed above do not necessarily represent the degree of density of traffic concentration because of the comparatively large areas of zones in the outlying area.

d) Future Traffic Assignment

The last step for estimating the future traffic volume is to make the traffic assignment on the basis of the future OD table and the future road network. Fig. 2-3-9 showing the present road network combined with the roads contemplated by Bangkok and Thon Buri is used as the future road network for the purpose of traffic assignment.

The traffic assignment is computed by the following method. A correlation expression of the traffic volume and the travelling speed is established in advance for each section of roads shown on Fig. 2-3-9. Then, the route of shortest travelling time was computed for each OD pair and a part of the traffic volume of the OD pair is assigned to such a path. As the travelling speed or the travel time changes in accordance with the traffic volume thus assigned, the shortest route was computed again. A part of remaining OD traffic volumes assigned in the second computation is added to that path. This process is repeated until all of the OD traffic volume is assigned. The traffic volume thus estimated for every section of every road is shown in fig. 2-3-10 (for 1975) and Fig. 2-3-11 (for 1990).

According to the result of the assignment, the traffic volume across the Mae Nam Chao

Phraya is 381,000 vehicles in 1975 and 854,000 vehicles in 1990, amounting respectively to 3.7 times and 8.3 times of 102,000 vehicles in 1969. These growth rates are more than those of the OD traffic volume between Bangkok and Thon Buri, that is 2.8 times for 1975 and 7.8 times for 1990. The reason may be found in Fig. 2-3-12. The details of the traffic across the Mae Nam Chao Phraya are shown by origins and destinations in Fig. 2-3-12, in which the first thing to be noticed is that the traffic in the Bangkok City, being very small at present, amounts to as much as about one third of the total in 1975 and declines to a little less than 20% in 1990. It means that the Tha Chang Br. and the Sathorn Br. added to the existing four bridges enable the traffic between points in the Bangkok City to reach the destination faster by a route detouring through Thon Buri. But, in 1990, the traffic between Bangkok and Thon Buri, which uses primarily the bridges, increases so that the capacity to take such a detour decreases with a consequent diminution in its proportion.

The traffic assignment amongst six bridges is as shown in Fig. 2-3-13.

As the traffic on the Memorial Br. has already reached its full capacity, it will scarcely change from 1975 to 1990. That the traffic volume is fixed does not mean that the traffic demand in the central business district is fixed.

On the other hand, the traffic volume on the Tha Chang Br. and the Sathon Br. grow so rapidly exceed 200,000 vehicles in 1990. But, such traffic volume can not be expected actually judging from their traffic capacities.

The maximum traffic volume that can be expected from the standpoint of traffic capacity will be nearly equal to the traffic volume on the Memorial Br. at present, that is 57,000 vehicles (excluding motorcycles) per 12 hours. The roadway of the Memorial Br. is 10m in width, and if it is deemed to have three lanes, each of them is to carry about 20,000 vehicles per 12 hours. The Tha Chang Br. and the Sathorn Br. will have six lanes, the Krun Thon Br. and the Krung Thep Br. have 4 lanes and the Rama 6 Br, two lanes. If these lanes are added to the three lanes of the Memorial Br., the six bridges over the Mae Nam Chao Phraya will have twenty-five lanes in total with the capacity being around 500,000 vehicles.

The traffic across the Mae Nam Chao Phraya will increase from 381,000 vehicles in 1975 to 854,000 vehicles in 1990. Assuming the traffic volume will increase uniformly throughout this period, it will increase by 32,000 vehicles in annual rate with a prospect to reach the level of 500,000 vehicles by about 1980. In that time, a traffic stagnation equal to that now being experienced on the Memorial Br. will arise on any of the six bridges. It may be concluded that an additional eighteen lanes are needed to meet the traffic demand in 1990. However, since this is a very important matter, a plan should be formed carefully after having carried out comprehensive and detailed surveys.

(3) The Sathorn Bridge and Related Road Network

a) The road network must be planned so as to carry the future traffic volume. It goes without saying that the future traffic volume is influenced by the road network; still an adequate and smooth traffic must be ensured. Since it is not easy to reinvest in roads, the reasonable planning of a road network should aim at the traffic volume in 20-30 years hence. The planning of the road network for 1990 is considered in the following.

As is seen in Fig. 2-3-14, the present traffic has its main sources of generation in Zones 1, 2, 3, 4 and 6 lying within a radius of about 3 km from Bangkok Central Station and the traffic is congesting in these areas. While in the future the present sources of traffic generation will spread wider to the outlying area with the progress of the development plan, as stated hereto-

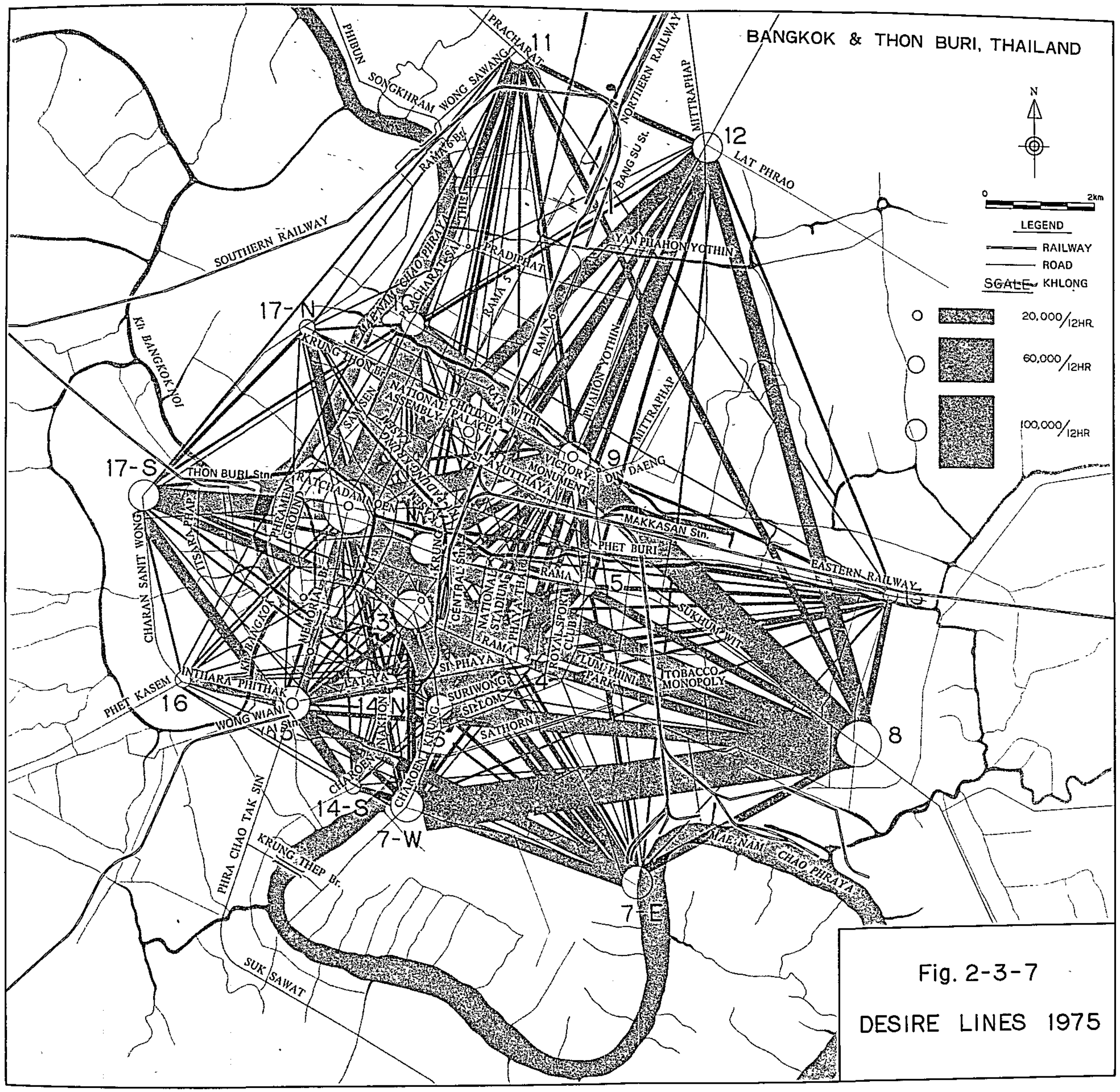


Fig. 2-3-7

DESIRE LINES 1975

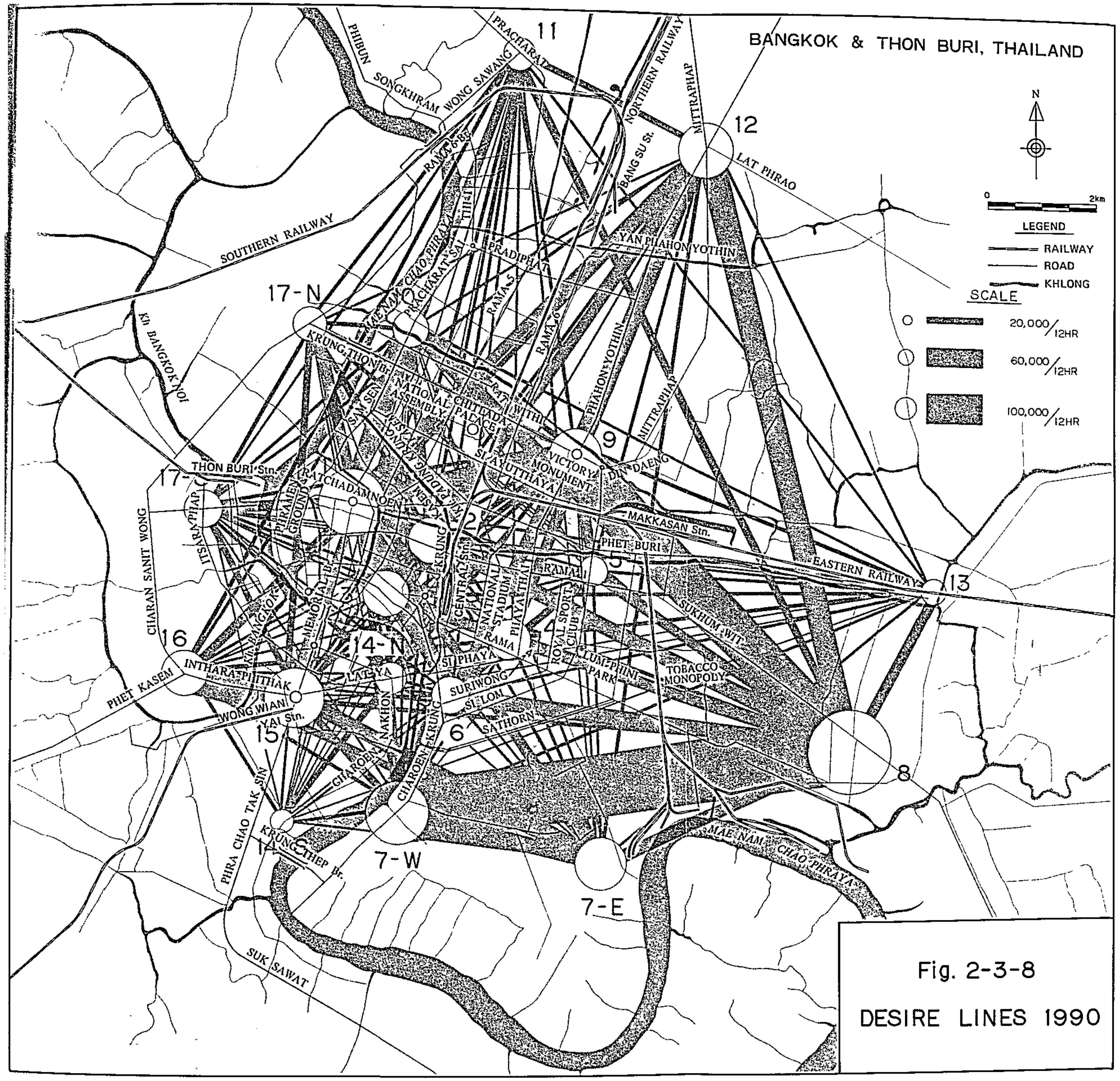


Fig. 2-3-8
DESIRE LINES 1990

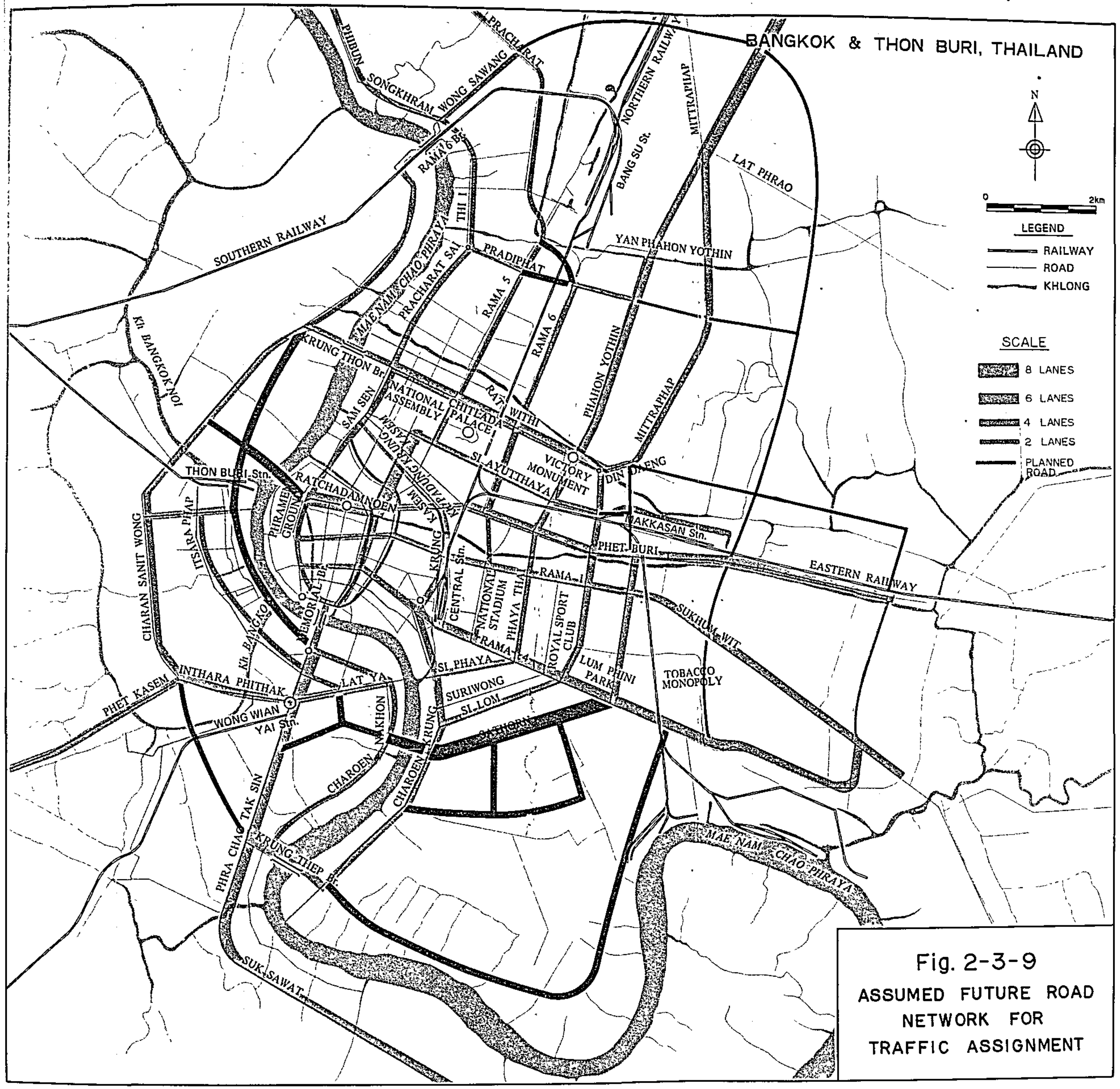


Fig. 2-3-9

ASSUMED FUTURE ROAD NETWORK FOR TRAFFIC ASSIGNMENT

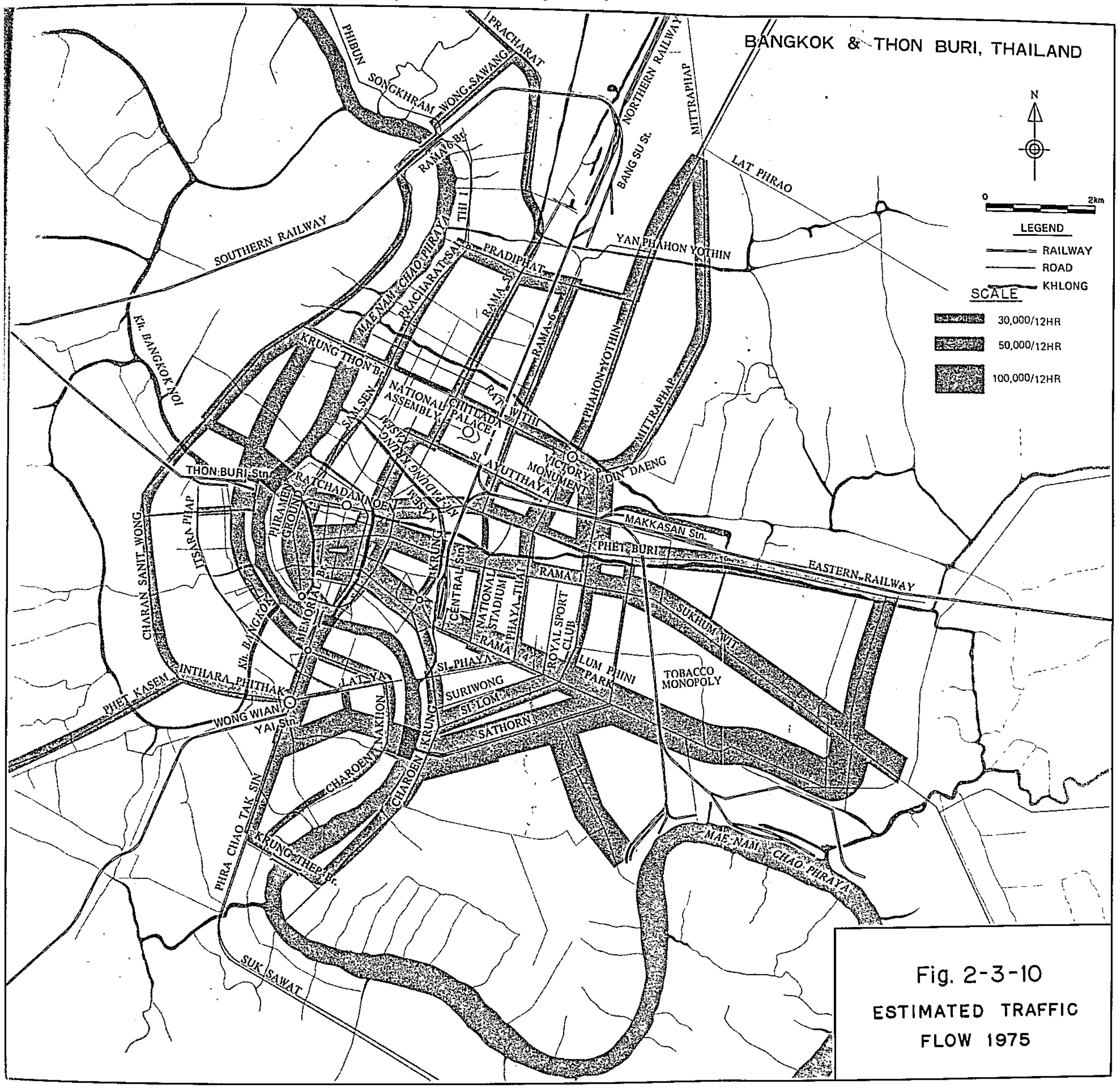


Fig. 2-3-10

ESTIMATED TRAFFIC FLOW 1975

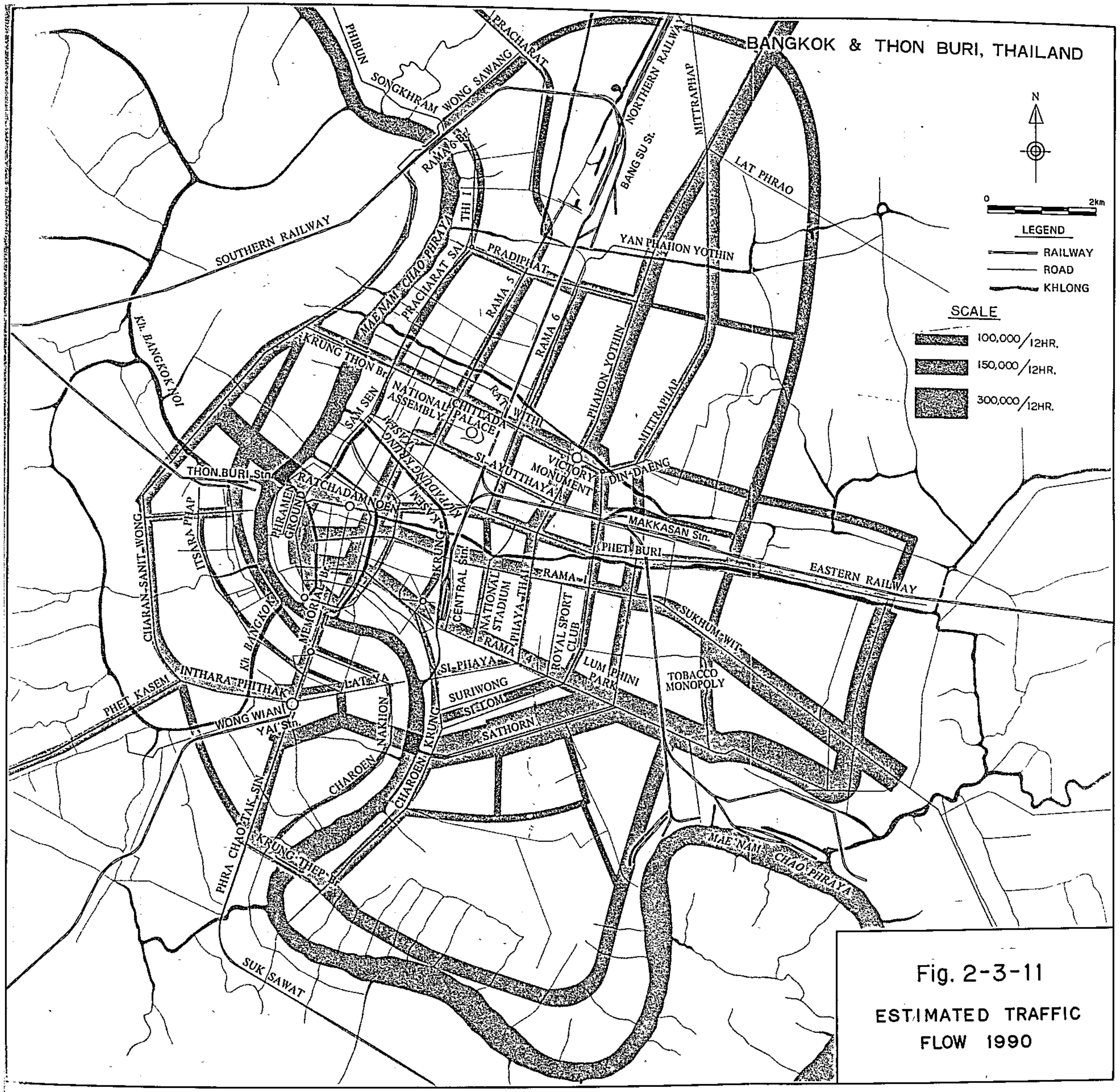
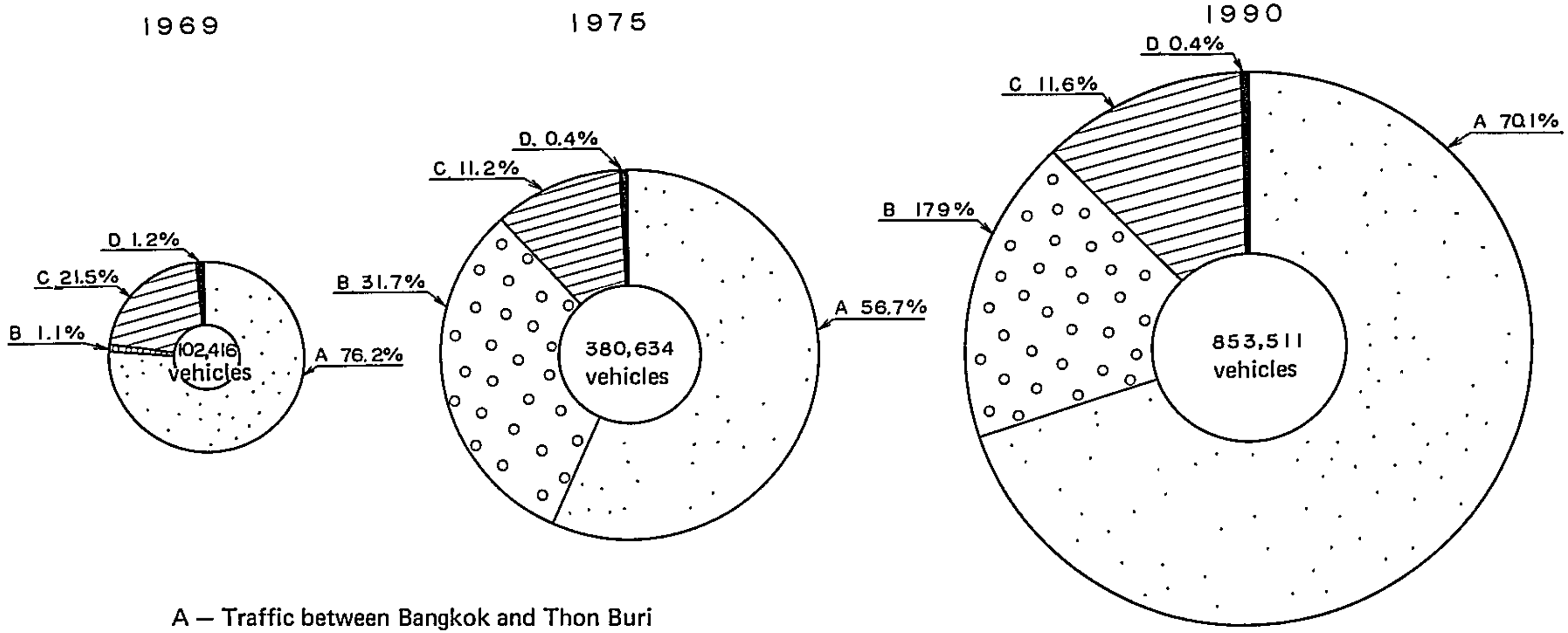


Fig. 2-3-11

ESTIMATED TRAFFIC FLOW 1990

Fig. 2–3–12 ESTIMATED CHANGE IN ORIGIN AND DESTINATION OF THE TRAFFIC ACROSS THE MAE NAM CHAO PHRAYA



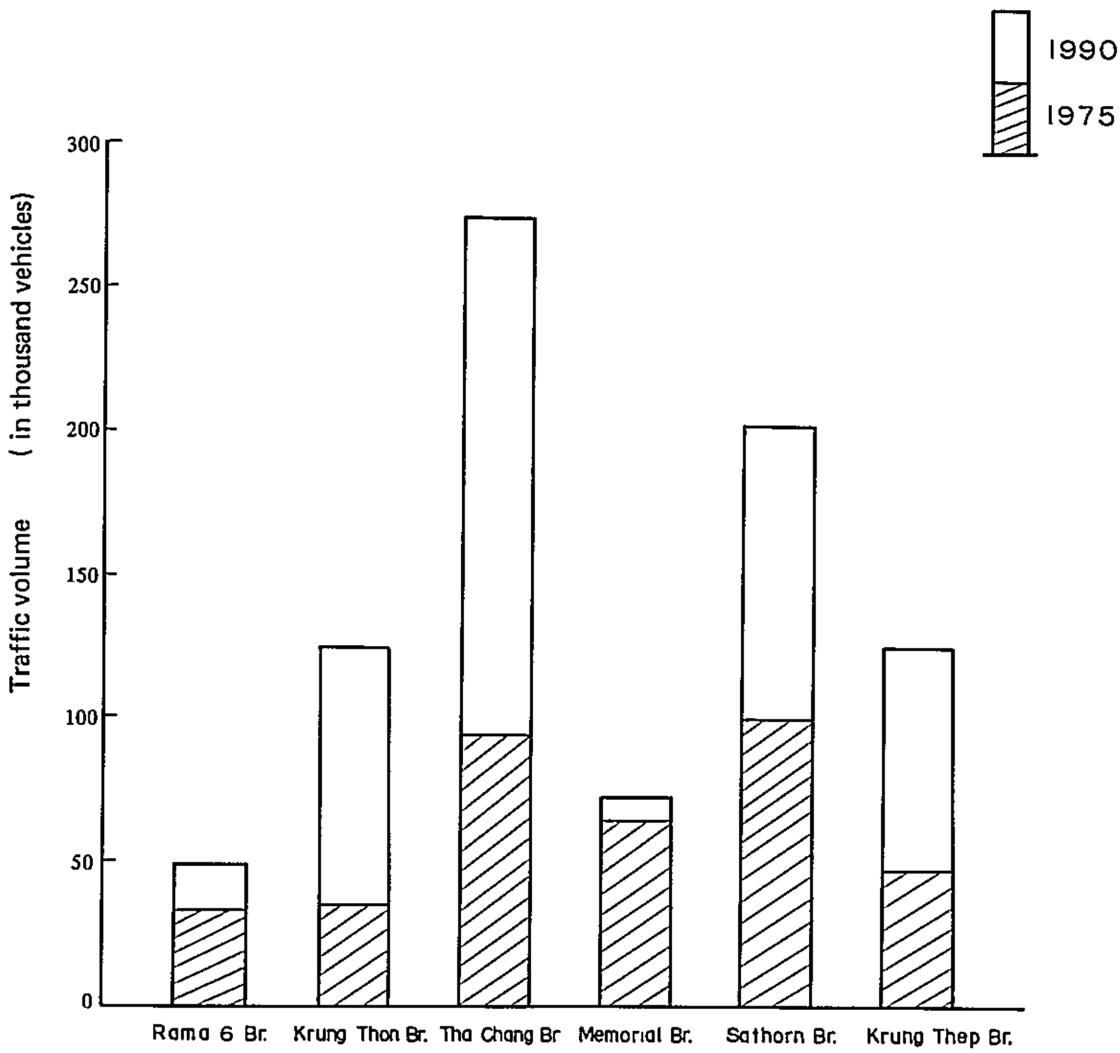
A — Traffic between Bangkok and Thon Buri

B — Traffic in Bangkok or Thon Buri

C — Traffic flowing in or out of Bangkok or Thon Buri

D — Traffic passing through Bangkok and Thon Buri

Fig. 2–3–13 ESTIMATED FUTURE TRAFFIC VOLUME BY BRIDGES



fore. This stretch of traffic generating sources covers the areas lying within a radius of about 5 - 7.5 km from Bangkok Central Station. Though the intrazonal traffic of short distances cannot help using the roads in the central business district, there is no justification to allow the traffic flowing in from other district, or long distance traffic within the area to use the congested roads; it is advisable for such traffic to take a route capable of reducing travel time. If the present status is considered from this viewpoint, the main objects of the future road plan will be to improve the road network in the area and to constructring roads surrounding it.

The ring road on a radius of 5 km is planned to start on Charan Sanit Wong Rd. and to run via the Krung Thep Br., Bangkok Harbor, Sukhum Wit Soi 21, passing the east side of Makkasan Station to the north parallel with Mittraphap Rd., and to turn to the west passing Wong Sawang Rd. to connect with th Rama 6 Br. The estimated volume of traffic carried by this ring road is about 100,000 vehicles/12 hr. The road running along the Mae Nam Chao Phraya to connect the Krung Thep Br. with Bangkok Harbour which is planned as a wholly new road will need six lanes at least. Also it is desirous to plan a new road to link the above road along the river with the Sukhum Wit Soi 21. As the areas under development spread over the outside of that ring road, an outer ring road such as one on the radius of 10 km will be needed in the future.

It is very desirous to form a ring road on the radius of 3 km (via Sathorn Rd., Witthayu Rd., Ratwichi Rd., the Krung Thon Br., Charan Sanit Wong Rd. and Inthara Phithak Rd.) in line with the construction of the Sathorn Br. and its connecting roads. This ring road on the radius of 3 km is anticipated to carry a traffic volume more than 100,000 vehicles/12 hr. It may be desirous to connect Witthayu Rd. to Ratwichi Rd. to complete this ring road, but the latter road is now fairly congested and has houses densely built up along it so that it is very difficult to do. Therefore, it is inevitable to form the ring road using two roads connecting with Mittraphap Rd. and Si Ayutthaya Rd.

The road connecting Witthayu Rd. with Mittraphap Rd. will have an unfavorable alignment because the Makkasan Railway Shop will be located in between: however, it must take a comparatively easy course on the west side of the shop detouring its main portion by an elevated road. The southern end of Mittraphap Rd. is suitably designed to provide an approach to the elevated road. Although the elevated road is fairly close to Si Ayutthaya Rd., there seems to be a sufficient distance to take the structure of approach between them.

The construction of a bridge across the Mae Nam Chao Phraya and the improvement of streets will be needed for consolidating the road network in the area. In addition to the existing four bridges, two bridges, that is the Tha Chang and Sathorn Brs., are planned to cross the Mae Nam Chao Phraya. As the traffic volume on these bridges are expected to reach their capacities earlier than 1990, it seems necessary to construct another two or three bridges by 1980 at the latest. A more sufficient survey must be carried out before forming any plan. It is also desirable to strengthen the capacity of the street network by the improvement of intersections which constitute bottlenecks even now.

b) Role of the Sathorn Br. and Connecting Roads

The considerations so far reveal that the Sathorn Br. and its connecting roads are to play the following roles.

i) To take over the increased traffic in the future on the Memorial Br. which is saturated already with the present traffic.

ii) To constitute a trunk road to connect the southeastern part of Bangkok with Thon Buri City which are expected to develop in the future.

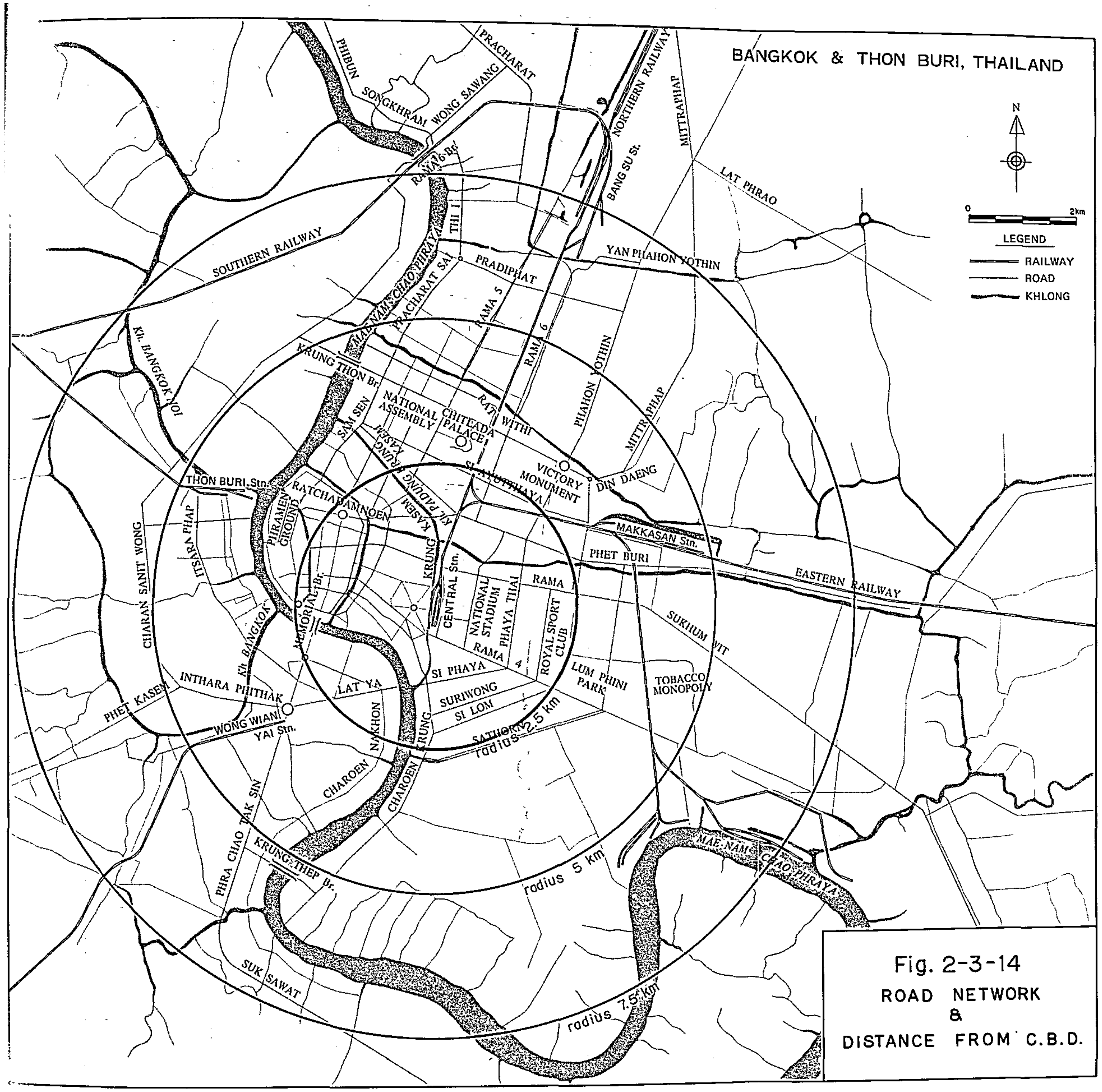
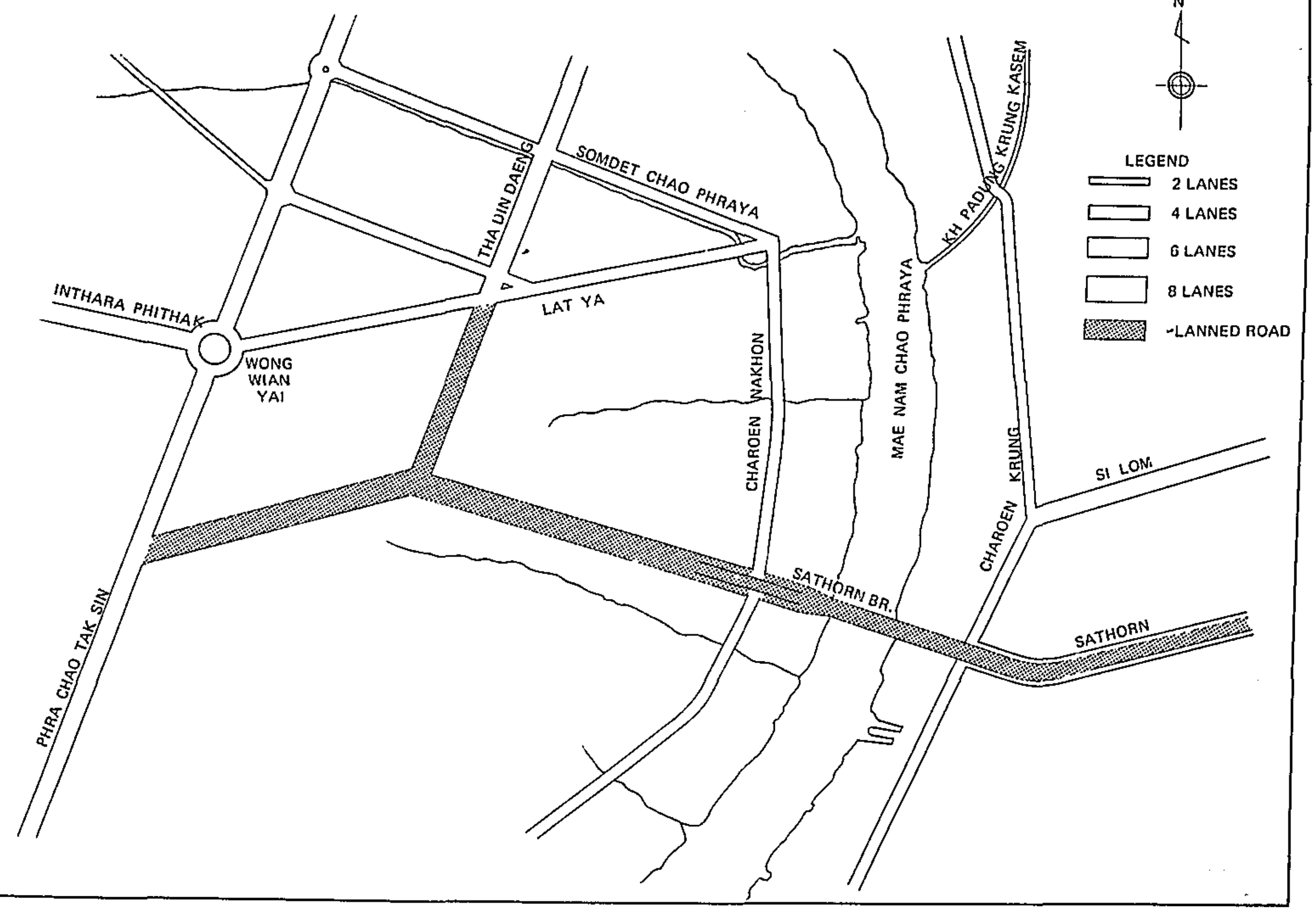


Fig. 2-3-14
ROAD NETWORK
&
DISTANCE FROM C.B.D.

Fig. 2–3–15 SATHORN BRIDGE & ITS APPROACHES



iii) To form a ring road to make through traffic bypass the city area and to distribute the flow-in traffic to the city roads.

The demend for traffic on the Sathorn Br. is estimated to be about 100,000 vehicles in 1975. The present survey has assumed that the construction work of the Sathorn Br. will begin after the completion of the Tha Chang Br. and open for traffic in 1975, though it is desirous to start the work as early as possible. Because the width of the Sathorn Br. depends on structural restrictions and the condition of its connecting roads, the bridge will have only six lanes in both directions in spite of pressing traffic demand. The connecting road will be joined to Sathorn Rd. on the Bangkok side to achieve the aforementioned object. Sathorn Rd. will become an eight-lane road by adding four new lanes to be built over the Khlong Sathorn. Charoen Krung Rd. already saturated with traffic will be over-crossed and will not be connected directly.

On the Thon Buri side, the approach will be directly joined to Charoen Nakhon Rd. as well as over-cross it by a 4-lane road. West of its the road will be a surface road having six lanes at least. On the other hand, since the Big Circle, the traffic center of Thon Buri, is carrying a great volume of traffic and is densely surrounded by houses, linking the connecting road directly with the Big Circle should be avoided. It is desirable to join the bridge to Phra Chao Tak Sin Rd. and also connect if with Lat Ya Rd. by a branch road.

It is necessary to deal with the traffic flowing out from the planned Paktho Highway by the ring road on the radius of 5 km constituted via the Krung Thep Br. or the ring road on the radius of 3 km constituted via the Sathorn Br.

2-4 Economic Justification of the Project

(1) Benefits

As the economic effects of a road construction, mention may be made of the direct effects such as reduction of transportation time, economy in travelling cost, improvement of comfort and decrease in traffic accidents, as well as the indirect effects such as advancement of land use, rationalization of production and transportation planning, development of resources and expansion of market. However, since it is not always easy to measure so many economic effects in terms of money, the general practice is to refer only to the reduction of transportation time (time benefit) and the economy in travelling costs (cost benefit) for working out those benefits. Such practice has been followed in this report.

For the purpose of estimating the amounts of these two benefits, the OD traffic volume of 1975 was assigned to the road network respectively in the case where the Sathorn Br. and its connecting roads will have been constructed and in the case where they will have not been constructed, to find road sections used by each OD pair and travelling distances between an origin and a destination.

The travelling distance of an OD pair using the Sathorn Br. is reduced by the difference between the travelling distance in the road network not including the Sathorn Br. and that in the road network including it. The reduction in the travelling distance of that OD pair is the product of the above difference multiplied by the traffic volume using the Sathorn. Br. of that OD pair. The sum of this product of each OD pair is nothing else but the total reduction in travelling distances owing to the construction of the Sathorn Br.

The above calculating processes are detailed in the separate report. The results of the calculation are shown on Table 2-4-1 which reveals that the differences in travelling distances amount to 129,000 vehicle-km for passenger cars, 239,000 vehicle-km for taxis and

161,000 vehicle-km for trucks, or 529,000 vehicle-km in all. These differences are nothing but the reduction of travel distance effected by the construction of the Sathorn Br.

On the other hand, the savings in travelling time resulting from the reductions in the travelling distance, with the travelling speed assumed to be 35 km/hr. for passenger cars and taxis and 30 km/hr. for trucks, are 222,000 minutes for passenger cars, 409,000 minutes for taxis and 322,000 minutes for trucks, or 953,000 minutes in all as shown on the bottom line of Table 2-4-1.

These are the reductions in the travelling distances and the savings in travel time resulting from the former, though it is believed that the actual cost and time benefits will be greater than these figures.

The road sections to be reviced in the road network for the traffic assignment, that is the Sathorn Br. in addition to three connecting roads - the new 4-lane Sathorn Rd. to be constructed utilizing the Khlong Sathorn (meaning the present 4-lane road is widened to an 8-lane road), a road over-crossing Charoen Nakhon Rd. to join to Phra Chao Tak Sin Rd. and a road branching off from the middle the second road to connect with Lat Ya Rd. - form only a small portion of the whole network in the Metropolitan Area. Nevertheless, their existance has complicated influences on the travelling routes, distances speed, and travel time for every OD pairs. Even if there is no change in the travelling route, namely the travelling distance, the travelling speed may well vary. If the travelling speed is accelerated, thanks to the construction of the Sathorn Br., the travel time will naturally be reduced. The travelling speed also effects a change in travelling cost as the latter is determined by the former. Furthermore, because the travelling costs are very great at low speeds and have a tendency to diminish temporarily with the increase in speed, the increase in travelling speed will mean the reduction of travelling costs in case the traffic demand is great as compared with the traffic capacity.

Thus the construction of the Sathorn Br. will bring about cost and time benefits not only as a result of the reduction in travelling distance but because of the increase in travelling speed. Particularly, the latter benefit is expected to arise for the traffic not making direct use of the Sathorn Br. Since the estimation of the travelling speed on which the latter benefit is calculated is very difficult to estimate for all the road sections in the Bangkok - Thon Buri Metropolitan Area, only the direct benefits mentioned first are referred to as the benefits from the Sathorn Br.

The next step was to determine the unit prices of the time value and the travelling cost to express the estimated reductions of travel time and travelling distance in terms of money. As these values vary with the difference in conditions of countries, those prevailling in Japan were modified so as to fit the conditions of Thailand.

The unit time values used generally in Japan are shown on Table 2-4-2. As these values are regarded to be in proportion to the GNP or the income per capita, they were multiplied by 0.159 or the ratio of GNP per capita of Thailand to that of Japan shown on Table 2-4-3. On the assumption that the ratio of ordinary and small vehicles are 0.2 : 0.8 for passenger cars and taxis and 0.5 : 0.5 for trucks, the unit time value of ฿0.0529/minute for passenger cars and taxis and that of ฿0.0537/minute for trucks were found as shown on Table 2-4-2.

The standard formula prevailing in Japan was used to calculate the travelling cost applying the values of Thailand to it. The calculation of the unit travelling costs and its results are shown on Table 2-4-4. The travelling cost includes such cost items as fuel, lubricants, tyres and tubes, depreciation of vehicles and repairs, and for each of them the cost per km excluding tax was calculated on the basis of price, durable distance and rate of tax. As the durable distance was applied to that of the ordinary streets in Japan and as the price and the tax rate were used the standard values in Thailand. While the lubricant cost was simply fixed at 10% of the fuel cost in accordance with the practice in Japan. Besides this, the administrative and personnel expenses must be added to the above direct costs of five items. In Japan, these expenses are calculated at fixed rates of the direct costs, so these rates were used after having modified by the ratio of GNP per capita shown on Table 2-4-3. As the result of these calculations, the unit travelling cost of passenger cars and taxis was found to be ฿0.696/km and that of trucks ฿1.719/km. The reason why the cost, excluding tax, was computed is that while the tax is merely transfer of money from people to national finance the benefits mentioned above mean a profit or a reduction in cost for the national economy as a whole.

The estimated time benefits and cost benefits which are shown on Table 2-4-5 were worked out from the total travel time and total travelling distance to be reduced in 1975 as a result of the construction of the Sathorn Br. and the unit time value and unit travelling cost as above calculated. The time benefits being ฿12,000 for passenger cars, ฿22,000 for taxis and ฿18,000 for trucks making a total of ฿52,000; the cost benefits being ฿90,000 for passenger cars, ฿166,000 for taxis and ฿277,000 for trucks making a total of ฿533,000. Since these benefits amounting to ฿584,000 in the aggregate represent the sum per day, the amount for the year will be

฿584,482/day x 365 days = ฿213,000,000.

Strictly speaking, the benefits above computed should represent the values for 12 hours in the daytime because all the estimations of traffic volume were made on the basis of equivalent values. But the benefits in the nighttime were neglected as their total is believed to be fairly small because the traffic volume decreases sharply at night and the increased speed reduces both the time and cost benefits per vehicle.

(2) Costs

Costs necessary for the proposed project include the construction and maintenance costs of the Sathorn Br., the widened portion of Sathorn Rd. on the Bangkok side and the two connecting roads on the Thon Buri side.

The cost for constructing the Sathorn Br. is estimated roughly at ฿297,000,000 in Chapter 3-4 of this report.

The construction cost of the two connecting roads on the Thon Buri side will be estimated very roughly with reference to costs of any other road project as follows.

The total cost for constructing the Paktho Highway is estimated at about ฿240,000,000. Its length being 82.1 km, the construction cost per km of the Paktho Highway is:

$$\frac{฿240,000,000}{82.1 \text{ km}}$$

= ฿2,800,000/km.

Assuming that the connecting roads on the Thon Buri side will have eight lanes as compared with two lanes of the Paktho Highway, the construction cost of the connecting roads on the Thon Buri side is:

$$฿2,800,000/\text{km} \times \frac{8}{2}$$

=฿11,200,000/km.

The cost for the right-of-way on the basis of ฿80/m^2 in the unit cost and 80m in the width is:

฿80/m^2 x 80m x 1 km

=฿6,400,000/km.

Accordingly, the project cost of the connecting roads on the Thon Buri side is:

Table 2-4-1 Reduction in Travel Distance and Time due to Completion of the Sathorn Br.

Items \ Vehicle type	Passenger car	Taxi	Truck	Total	Remarks
Reduction in travelling distance (veh-km)	129,469	238,528	160,876	528,873	Based on the traffic assignment
Reduction in travel time (veh.-min.)	221,947	408,905	321,752	952,604	The reduced distance was converted into time on the basis of speed at 35 km/hr. for passenger cars and taxis and 30 km/hr. for trucks

Table 2-4-2 Unit Time Value

Items \ Vehicle type	Passenger car & taxi		Truck	
	Ordinary	Small	Ordinary	Small
Unit value in Japan (฿/min.)	0.438	0.306	0.453	0.267
Unit value in Thailand (฿/min.)	0.0696	0.0487	0.0720	0.0425
Ratio of ordinary and small vahicles	0.2	0 8	0.5	0.5
Unit time value (฿/min.)	0.0529		0.0573	

Table 2-4-3 Per Capita GNP of Thailand and Japan

Items \ Country	Thailand	Japan
GNP★ (฿1,000,000)	96,269	1,955,841
Population (1,000 persons)	32,680	100,428
GNP per capita (฿ /person)	2,946	18,478
Ratio	0.159	1,000

Note: ★ at 1962 prices

Table 2-4-4 Unit Travelling Cost

Vehicle type	Passenger cars & taxis				Trucks				Remarks
Standard travelling time	35 km/hr.				30 km/hr.				
Cost items	Unit Value (Including tax)	Durable distance	Rate of tax	Travelling cost excluding tax (฿/km)	Unit Value (including tax)	Durable distance	Rate of Tax	Travelling cost excluding tax (฿/km)	
Fuel	Gasoline ฿ 2.2 /litre	11 4km	0 45	0.106	Light oil ฿ 1.4 /litre	3.6km	0.17	0.323	
Lubricants	–	–	–	0.011	–	–	–	0.032	Calculated at 10% of fuel cost
Tires & tubes	฿ 330 /pc.x 4pcs.	35,200 km	0.17	0.031	฿ 1,600 /pc.x 6pcs.	60,000 km	0.17	0.133	
Depreciation of vehicles	฿ 60,000	76,000 km	0.47	0.418	฿150,000	200,000 km	0.19	0.608	
Repairs	฿ 0.144/ km	–	0.15	0.122	฿ 0 344/ km	–	0.15	0.284	Used values in Japan
Total direct costs	–	–	–	0.688	–	–	–	1,380	
Administrative and personnel expenses	–	–	0.011	0.008	–	–	0.246	0.339	Values shown under the heading of rete of tax are the rates to direct cost
Total travelling cost	–	–	–	0.696	–	–	–	1.719	

Note (1) The values of standard travelling speed and durable distance are those on the ordinary streets in Japan
(2) Unit values and rates of tax are the average values in Thailand.

Table 2-4-5 Benefit per Day Derived from Proposed Project

Items		Vehicle type: Passenger car	Taxi	Truck	Total
Time benefit	Reduction in travelling time (veh.-min.)	212,947	408,905	321,752	952,604
	Unit value (฿ /veh.-min.)	0.0529	0.0529	0.0573	–
	Amount (฿)	11,741	21,631	18,436	51,808
Cost benefit	Reduction in travelling distance (veh.-km.)	129,469	238, 528	160,876	528,873
	Unit value (฿ /veh.-km)	0.696	0.696	1.719	–
	Amount (฿)	90,110	166,015	276,549	532,674
Total Benefit (฿)		101,851	187,646	294,985	584,482

฿11,200,000/km + ฿6,400,000/km

= ฿17,600,000/km

On the other hand, though the cost per kilometer of road project in Bangkok and Thon Buri varies somewhat according to each road, the average amount is about ฿5,300,000/km for a road of 30m in width of which 9.5m (two lanes) is paved. If the ratio of construction and land costs included in this average amount is deemed the same as that of the project cost calculated on the basis of the construction cost of the Paktho Highway, that is

11,200,000 : 6,400,000 = 0.64 : 0.36,

the project cost of the connecting roads on the Thon Buri side which are 80m wide with eight paved lanes will be:

$$฿5,300,000/km \times (0.64 \times \frac{8}{2} + 0.36 \times \frac{80}{30})$$

= ฿18,700,000/km.

Therefore, the project cost of the connecting roads is estimated at ฿18,000,000/km, which is approximately the average figure of ฿17,600,000/km on the basis of the estimated cost of Paktho Highway and ฿18,700,000/km on the basis of the average cost of roads projects in Bangkok and Thon Buri.

The next step is to estimate the project cost of the widened portion of Sathorn Rd. As it is to be constructed on the Khlong Sathorn with four lanes, its project cost is calculated from that of connecting roads on the Thon Buri side, subtracting the land cost of ฿6,400,000 /km from it and on the basis of four lanes instead of eight lanes.

The construction cost of the widened road surface of Sathorn Rd. is:

$$(฿18,000,000/km - ฿6,400,000/km \times \frac{4 \text{ lanes}}{8 \text{ lanes}}$$

= ฿5,800,000/km.

In addition, for covering costs such as those for box culvert and piles required to fill up the Khlong Sathorn, an allowance of ฿32,000,000 is deemed to be sufficient. Thus, the total of cost for constructing the road surface and filling up the canal is set at ฿38,000,000/km.

The total cost of the project including the Sathorn Br. and the three connecting roads is estimated at ฿456,000,000 as seen in Table 2-4-6.

Finally, the maintenance cost of the construction project is estimates.

Among the costs for maintaining the Sathorn Br., that for preserving the function of road are shown on Table 2-4-7 in approximate sums.

The cost includes such items of expense as minor repairs, paving, electricity for illuminating, lane marks and so on. The total maintenance cost calculated by items from the actual unit cost in Japan multiplied by the length of the Sathorn Br. amounts to an average of ฿192,000 per year.

The maintenance cost of the connecting roads from which the item of expense for minor repairs should be excluded is assumed to be proportional to the number of lanes and the length of the road. Such cost amounts to ฿328,000 for widening a portion of the Sathorn Rd., and ฿547,000 for the two roads on the Thon Buri side. The maintenance cost of the movable portion of the Sathorn Br. is estimated at about ฿66,000 in Chapter 3-4 of this report.

The above estimates are put together on Table 2-4-8 to calculate the total maintenance cost of the proposed project which amounts to ฿1,133,000.

Table 2-4-6 Cost of Proposed Project

Construction	Unit cost (B1,000,000)	Length (km)	Amount (B1,000,000)
Sathorn Br.	–	1.1	297
Two connecting roads on the Thon Buri side	18	2.5	45
Widening of Sathorn Rd.	38	3.0	114
Total	–	–	456

Table 2-4-7 Road Maintenance Cost of the Sathorn Br.

Items		Unit cost	Quantity	Amount (฿/year)	Remarks
Painting, Joints, minor re-pair, etc.		฿1.44/m-lane-year	roadway footway 1,107m x 6+313 x 2 = 7,268m	10,466	The actual value of Meishin Expressway : 5.78/m - 4 - lanes - year Footway is considered as one lane.
Bituminous pavement	Patching	฿0.72/m^2-year	1,107m x 21m + 313m x 2.5m x 2 = 24,812m^2	17,865	The mean unit cost is used as the cost increases year by year as shown below.
	Re-sur-facing	฿63.55/m^2-15year		105,120	As it is required once for 15 years, the annual amount is one fifteenth of the calculated amount.
	Total	–		122,985	
ane mark-ing		฿4.04/m - year	1,107m x 5 = 5,535m	22,361	
Illumi-nation electri-city		฿0.58/Kw -hr.	0.4Kw x 55pcs. x 10hr./day x 365days x 0 6	27,944	The lighting rate is 60% as the illumination is reduced at midnight.
Others		–	–	18,376	It is put at 10% of the total of the above amounts.
Grand total		–	–	192,132	

No. of years passed	1	2	3	4	5	6	7
Unit cost (฿/m^2)	0.23	0.46	0.52	0.58	0.64	0.69	0.75

8	9	10	11	12	13	14	Mean
0.81	0.87	0.87	0.92	0.92	0.98	0.98	0.72

Table 2-4-8 Maintenance and Operation Cost of the Sathorn Br.

Items / Maintenance cost		Length (km)	No. of lanes	Maintenance cost(฿1,000)	Basis of calculation
Road surface on the Sathorn Br.		1.11	6	192	Table 2-4-6
Connecting Roads	Widened portion of Sathorn Rd.	3.0	4	328	$(192-10) \times \frac{3.0km}{1.11km} \times \frac{4 \text{ lanes}}{6 \text{ lanes}}$
	Two roads on Thon Buri side	2.5	8	547	$(192-10) \times \frac{2.5km}{1.11km} \times \frac{8 \text{ lanes}}{6 \text{ lanes}}$
Movable portion of the Sathorn Br.		–	–	66	Chapter 3-4 of this report
Total		–	–	1,133	

(3) Economic Feasibility of Proposed Project

With the prupose of studying the feasibility of the proposed project, the comparison of the benefit and cost ascertained in the foregoing paragraphs is made in the following.

The method of cost-benefit ratio and that of internal rate of return are used for the present purpose. But, the term of redemption of the project cost shall be 20 years, and though the said cost is believed to be disbursed from 1972 - 1974 as the construction of the Sathorn Br. takes three years as stated in Chapter 3-5 of this report, an assumption is made for the convenience of calculation that the total amount is invested in 1973. Further, though the benefit increases in proportion to the growth in the traffic volume (in the manner of geometric progression), the latter is deemed to be constant from 1980 onward due to restriction imposed by the capacity.

The calculation of cost-benefit ratio is expressed in the following formula:

$$C = \frac{i(1+i)^{n+2}}{(1+i)^n - 1} Cc + Mc$$

C - Equalized annual cost

Cc - Construction cost of the proposed project. The factor applied to this cost is called 'capital recovery factor', and the product of it and the construction cost means the equalized amount of annual redemption of the latter; but the exponent of the numerator is modified by +2, as the construction cost is invested two years before opening of the bridge for traffic.

Mc - Maintenance cost of the proposed project

i - Annual rate of interest

n - Term of redemption

$$B = \frac{i(1+i)^n}{(1+i)^n - 1} \sum_{k=1}^{n} (1+i)^{-k+1} Bk$$

B - Equalized annual benefit

Bk - Benefit in Kth year

If it is assumed that the benefit in the first year of opening for traffic increases in the manner of geometric progression for a certain period and stays at a fixed amount thereafter, the above last formula may be expressed in another way, as follows:

$$B = \frac{i(1+i)^n}{(1+i)^n - 1} \times B_1 \times \left\{ \sum_{k=1}^{m} \left(\frac{1+h}{1+i}\right)^{k-1} + \sum_{k=m+1}^{n} \frac{(1+h)^m}{(1+i)^{k-1}} \right\}$$

$$= \frac{i(1+i)^n}{(1+i)^{n-1}} \times B_1 \times \left\{ \frac{1 + \left(\frac{1+h}{1+i}\right)^m}{1 - \frac{1+h}{1+i}} + \left(\frac{1+h}{1+i}\right)^m \times \frac{1 - \frac{1}{(1+i)^{n-m}}}{\frac{i}{1+i}} \right\}$$

B_1 - Benefit in the first year of opening for traffic

m - No. of years for which the benefit continues to grow

h - Growth rate of benefit

The cost-benefit ratio to be found is as follows:

$$r = \frac{B}{C}$$

r - Cost-benefit ratio

The estimates of cost and benefits of the proposed project made so far have been given the following values necessary for working out the equalized annual cost (C) and equalized annual benefit (B)

Cc = ฿456,000,000 (see Table 2-4-6)

Mc = ฿ 1,133,000 (see Table 2-4-8)

n = 20

B_1 = ฿213,000,000 (see Chapter 2-4 (1))

m = 5

h = 0.0481 (assigned traffic on the Sathorn Br. based on 100,670 vehicles for 1975 and 203,778 vehicles for 1990)

If the rate of interest is put at 8% and 12%, the cost-benefit ratios are respectively 5.0 and 3.6 as shown on Table 2-4-9.

Either of the cost-benefit ratios are very great as compared with those of ordinary road construction. It is believed that in Thailand the traffic facilities are insufficient as against the traffic volume, and in particular, more bridges are keenly needed to cross the Mae Nam Chao Phraya.

Another comparison is made by the method of the internal rate of return. This is the method to find a discount rate which makes the assessed current value of the cost equal to that of the benefit, that is the internal rate of return.

The calculation is expressed as the following formula:

$$Cc + \frac{Mc}{(1+i)^2} \sum_{k=1}^{n} \left(\frac{1}{(i+i)^2}\right)^{k-1} = \frac{1}{(1+i)^2} \sum_{k=1}^{n} \frac{Bk}{(1+i)^{k-1}}$$

i - Internal rate of return

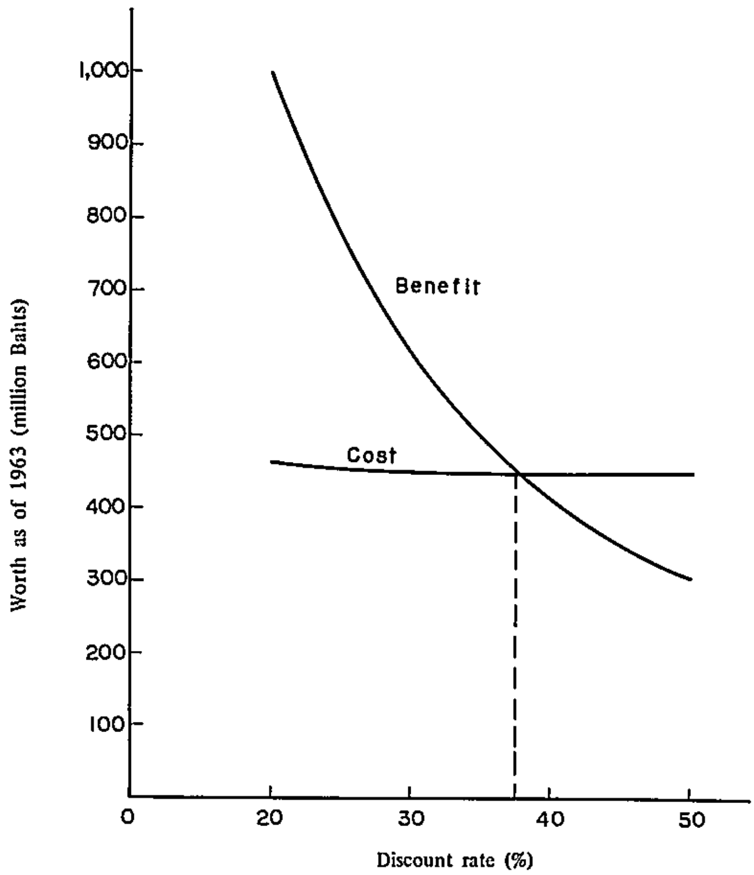
The left side of this formula represents the assessed current value of the cost and the right side that of the benefit. Fig. 2-4-1 is the graph generated by these values and shows that the internal rate of return to be found is 38%. This internal rate of return is far greater than that expected in general.

Thus, both the cost-benefit ratio and the internal rate of return show high values and assure the proposed project to be very beneficial from the viewpoint of the national economy of Thailand.

Table 2-4-9 Cost-Benefit Ratio

Rate of interest	Equalized annual cost (฿1,000,000)	Equalized annual benefit (฿1,000,000)	Cost-Benefit ratio
8%	55.3	274.9	4.97
12%	77.7	281.5	3.62

Fig. 2–4–1 INTERNAL RATE OF RETURN



CHAPTER 3 PRELIMINARY DESIGN OF THE SATHORN BRIDGE AND ITS APPROACHES

3-1 General Considerations

(1) Design Requirements

The following are the major requirements set by the Department of Public and Municipal Works, Government of Thailand, for the proposed Sathorn Bridge:

1) to provide the central span with a sufficient navigation clearance that allows a ship having a 30 m high mast to pass freely,
2) to provide each span over the river with a clear span of not less than 60 m,
3) to adopt the use of reinforced concrete or prestressed concrete for the entire bridge except for the central span,
4) to give due consideration to the beauty of Bangkok City, and
5) to select structures that incur the minimum cost for maintenance and operation.

To begin with, both a cross-river tunnel and a bridge were considered as a means of crossing the river in the rough draft. The cost estimation revealed that the tunnel, though preferable for navigation, would not only incur a higher cost for construction, maintenance and operation, but it would also be quite difficult to construct connections to the existing roads. Therefore, a tunnel is not advisable.

With respect to the type of bridge, a comparative study of the movable bridge and the fixed bridge led to the conclusion that the former should be adopted because the latter would not only demand extremely long extensions of approach due to the large clearance under the girder, but also would spoil the beauty of the city.

After discussions with the Department of Public and Municipal Works, a comparative study was made on the bascule type and the lift type for the central span, considering the width, clearance and other conditions. The study on the side span structure were limited to the P.C. structure in view of the 60 m span length.

As for the substructure, the rough drafts were prepared on the basis of the presumed soil conditions induced from the limited data of boring surveys conducted in the past near the construction site.

The caisson foundation and the pile foundation are generally used for the main span substructure. In the case of the proposed Sathorn Bridge, the maximum river depth at the construction site is as much as 19 m. This means that the type of foundation for this bridge must be determined after due consideration is given to the construction method.

The caisson foundation can be constructed either by the artificial island method or the floating caisson method. The former method is applicable to the side span, while the latter is more advantageous for the central span due to the great water depth. Hence, the application of these two methods to respective cases were studied.

For the pile foundation, there are two applicable methods, i.e., the cast-in-place concrete pile method using the reverse-circulation drill and the steel pile method. In this report, however, studies are made only on the former.

The prestressed concrete structure was adopted for the superstructure of approaches, while the pile foundation was employed in the substructure.

The scope of the design given in this report covers the road section between the points where the grade line meets the ground surface on both sides, which is approximately 1.1 km in length.

(2) Alignment

On the Bangkok side, the approach to the proposed bridge overcrosses Charoen Krung Rd. and connects with the 8-lane Sathorn Rd. which is to be built by remodelling the Khlong Sathorn as illustrated in Fig. 3-1-1. The width of Sathorn Rd., including the Khlong, is approximately 45 m, and does not require additional land expropriation for the remodelling. On the Thon Buri side, the approach overcrosses Charoen Nakhon Rd. and extends as a surface road until it connects with Phra Chao Tak Sin Rd. at a point about 500 m south of the Big Circle (See Fig. 2-3-15). And for the access from Charoen Nakhon Rd., two ramps (on-ramp and off-ramp) are provided with at the end of the main bridge on the Thon Buri side.

As for the vertical alignment, the maximum grade of 5% is applied at the ends of the approaches, while an ample navigational clearance over the Chao Phraya and sufficient vertical clearances over both Charoen Krung Rd. and Charoen Nakhon Rd. are provided. (See Fig. 3-1-2)

Fig. 3–1–1 TYPICAL CROSS SECTION OF SATHORN RD.

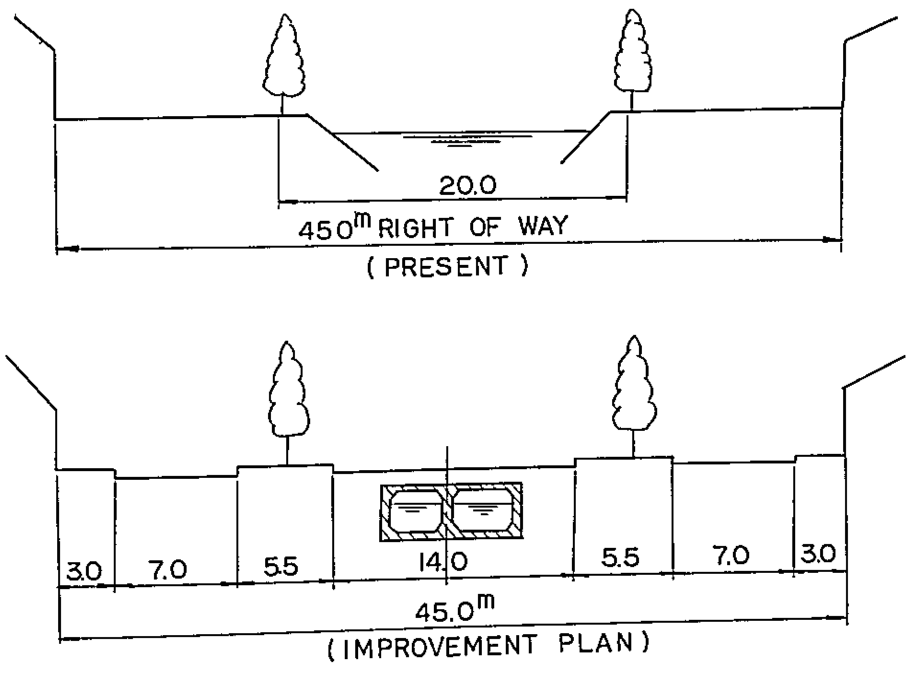
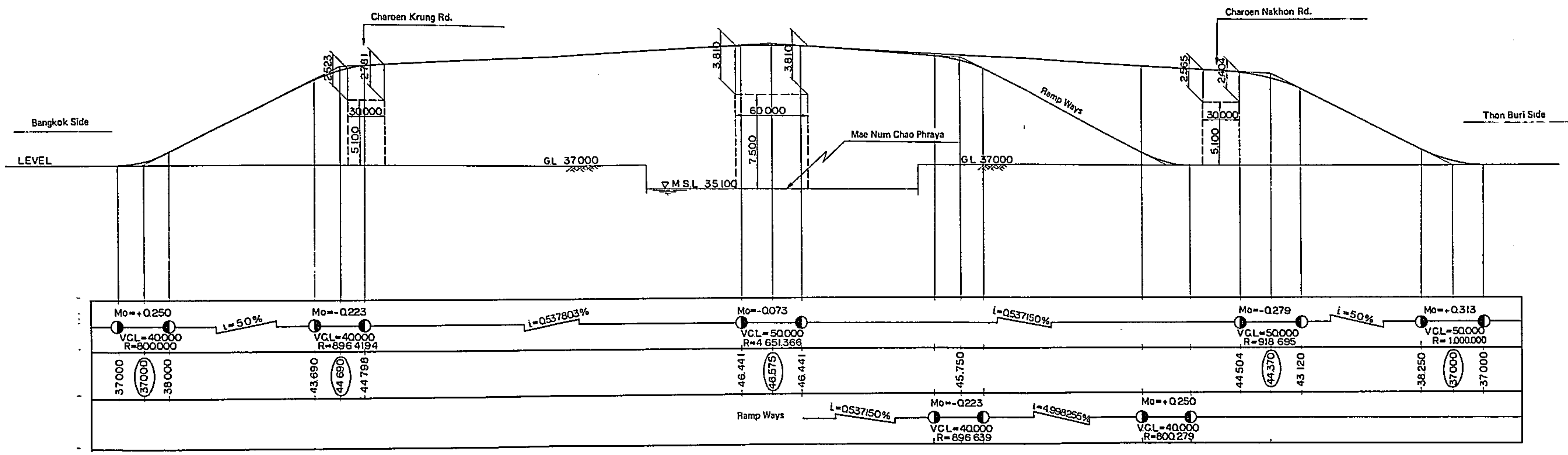


Fig. 3-1-2 VERTICAL ALIGNMENT

Scale H = 1 : 2,000 V = 1 : 200



The longitudinal gradient of the ramp way to Charoen Nakhon Rd. is 5%. The ramp way is to be provided with vertical curves on both ends and also with level sections of about 10 m, as shown in Fig. 3-1-1, between the end of the curve and Charoen Nakhon Rd. This vertical alignment makes it inevitable that the vertical curve must start at the main bridge, and consequently makes the structure of the main girder complicated. The structure of the main girder could be simplified if the vertical alignment was allowed to have a sag. Such a sag, however, would certainly form a so-called 'step' for drivers and is not desirable. The alignment illustrated in Fig. 3-1-2 has therefore been adopted.

(3) Restrictions on Construction Work

The prime consideration in scheduling the erection work is to assure free navigation on the Chao Phraya. This is required because the river plays, as already mentioned, an extremely important role as a transportation route indispensable not merely in Bangkok City but to the whole nation.

It has to be kept in mind that all Khlongs flowing into the Chao Phraya on both banks near the construction site are drainage channels. Among these, Khlong Sathorn deserves special attention because of the future plan to develop it into one of the main drainage channels in the city. The design and erection of the Sathorn Bridge should therefore be conducted with due regards to the function of this particular canal in the future sewage network of the city.

For the execution of erection work, a construction yard of suitable size must be secured in advance near the work site. Acquisition of such land does not seem easy on the Bangkok side where the road is narrow and houses are built so close to each other. Establishment of the required construction yard would entail less difficulty on the Thon Buri side because Charoen Nakhon Rd. running approximately parallel to the river is quite wide and has light traffic. In addition, very few houses are built on the bank. It must be noted, however, that some dredging work will be necessary for a large floating crane to dock at the bank.

3-2 Design Standards and Conditions

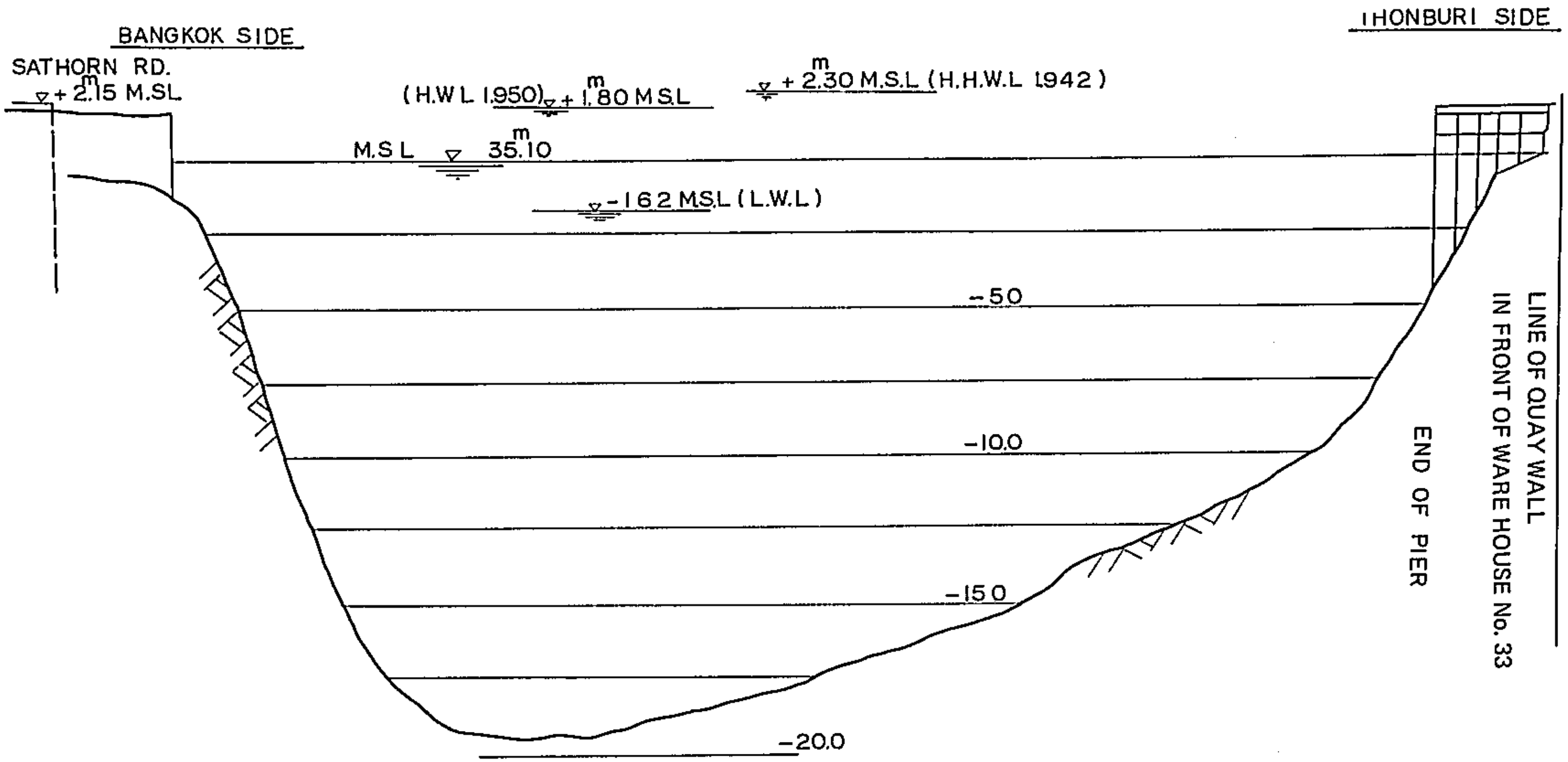
(1) Present Conditions of the Proposed Bridge Site

The vast plain extending around Bangkok is a low, level delta formed by the Chao Phraya. From the topographical conditions observed on this extensive plain, it is possible to draw an inference that Bangkok and its vicinities are stratigraphically composed of layers of alluvial soil running approximately horizontal.

At the construction site, the Chao Phraya is somewhat narrower than in the lower reaches and has a width of about 220 m. Therefore, the river is very deep near the bridge site and records M.S.L.–19.0 m in the deepest part of the river bed. Furthermore, as shown in Fig. 3-2-1, the deepest point is found a little closer to the Bangkok side.

The Chao Phraya, which meanders through the vast plain, has an exceedingly flat longitudinal slope (about 1/10,000). Its velocity, however, is relatively high near the construction site which is within the tidal compartment and subjected to a noticeable tidal range (max.: approx. 3.0m). The maximum flow velocity at the construction site is estimated to be about 2.5 m/sec.

Fig. 3-2-1 CROSS SECTION OF THE MAE NAM CHAO PHRAYA



The annual rainfall in Bangkok and its vicinities is about 1,530 mm. The year is divided into a wet season and a dry season, the former lasting from May to October and the latter covering the November-April period. The rainfall greatly varies from season to season, consequently, the water level is subjected to appreciable seasonal fluctuations.

The wind velocity in Bangkok and its surrounding areas is as shown in Table 3-2-1 which is the tabulation of observation data for the past 10 years. The table explicitly indicates that the wind velocity at the construction site is gentle throughout the year, and that there are very few occasions when strong winds threaten Bangkok.

Table 3-2-1 Observation for Mean & Maximum Speed of Surface Wind (Knot)

Period 1959 – 1968

Source: Meteorological Dept.

Month / Year	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT	NOV.	DEC	TOTAL	AVER-AGE
1959 ∫ 1968							MEAN SPEED (KNOT)							
	2.9	3 4	4 4	4.7	3.7	3 5	3.3	3 4	2.9	2.5	2.2	2.2		
							MAXIMUM SPEED (KNOT)							
	42.0	33.5	48.0	52.0	41.0	41.0	41 0	43.2	37.0	40 0	37.0			

Note: Maximum speed that has ever been observed 55.6 knots on April 1952 at Central Station (Sukhumvit Road)

(2) Geological Conditions

A geological survey by boring has not yet been undertaken at the proposed construction site. However, data of boring surveys conducted in Bangkok in the past serve to clarify that the soil condition is virtually uniform.

As a whole, an extremely soft clay with N value not exceeding 2 is found between the ground surface (approx. EL +37.00 m) and EL +20.00 m. Between EL +20.00 m and EL +12.50 m is a layer of hard sandy clay or clayey sand. N value of this layer ranges from 10 to 30, which is quite high, considering its clayey nature. This layer is underlain by a hard sandy layer, about 12.5 m in thickness and more than 25 in N value. Underneath this, or between EL 0.00 and EL −5.00 m, is found a layer of hard clay whose N value stands as high as 20 - 40. Still further below is an extremely hard gravel layer exceeding 40 in N value.

The second stratum is not considered to have a sufficient bearing capacity and is liable to be subjected to settlement due to consolidation. The third stratum is safe and solid enough to serve as the bearing stratum of an ordinary bridge. However, settlement of the underlying fourth stratum due to consolidation must be confirmed in numerical values to make sure that it gives no adverse effects to the surface structures. A numerical confirmation of settlement in the fourth stratum is to be one of the objectives of the boring survey required in the detailed stage of the design.

The fifth stratum of hard gravel, is highly recommendable as the bearing stratum. It has a large bearing capacity and is free from settlement due to consolidation.

The presumed geological condition of the construction site is as given above. The detailed design, it must be emphasized, should be preceded by the boring survey to check the bearing capacity of the third and fifth strata as well as settlement in the fourth stratum due to consolidation.

(3) Geometrical and Structural Design Specifications

(a) Cross-Section Elements

The roadway shall have 6 lanes, 3.5 m each, and the railing and barrier curb shall be 65 cm. Sidewalks of 2.5 m wide shall be installed on both sides of the main bridge between the pylons, and pedestrians shall descend by means of stairways to be constructed around the pylons on both banks.

The width of the ramps that connect the main bridge to Charoen Nakhon Rd. in Thon Buri shall be 6.5 m. The approach on the Thon Buri side shall be a 4-lane road. (See Fig. 3-2-3)

(b) Grade and Cross Slope

The maximum longitudinal gradient shall be 5%, and the cross slopes of the road way and sidewalk shall be 2% and 1.5%, respectively.

(c) Horizontal Alignment

A circular curve of 125 m in radius is inserted in the approach on the Bangkok side to best utilize the present right-of-way of Sathorn Rd. The alignment of the remaining section is straight.

(d) Vertical and Horizontal Clearances

Three spans, each having a navigational clearance of 60m, shall be secured over the Chao Phraya. The navigational Clearance of the central span under the girder, when closed, shall be 7.5 m above the M.S.L. The clearance under the girder of the lift bridge, when lifted, shall be 40 m above the M.S.L. (See Figs. 3-2-4 and 3-2-5)

Fig. 3–2–2 TYPICAL GEOLOGICAL LOG IN BANGKOK

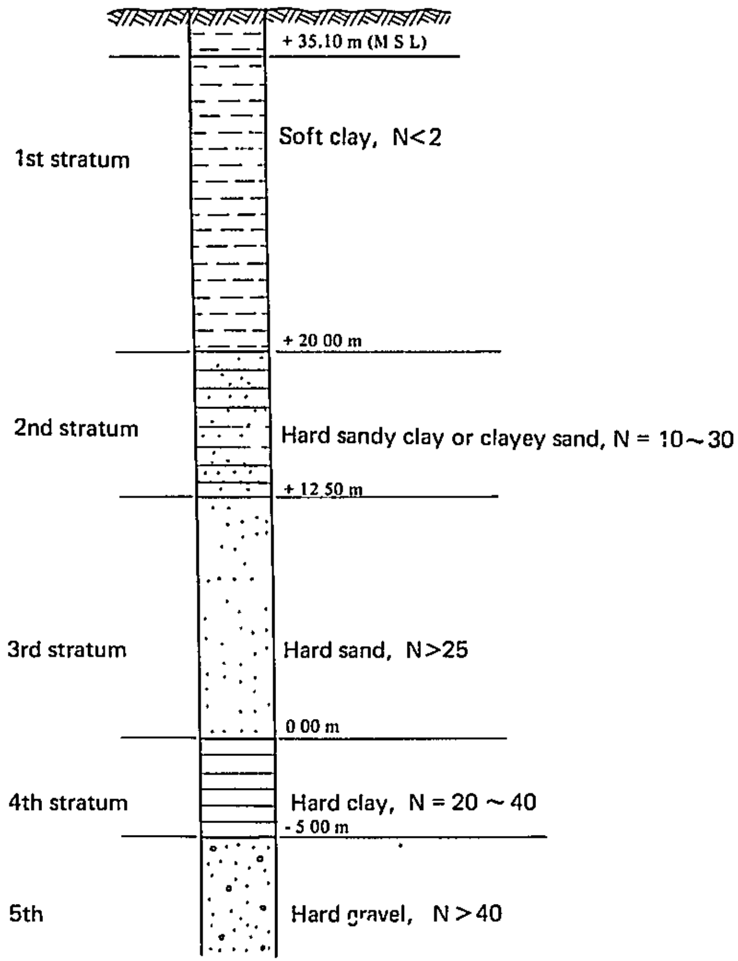
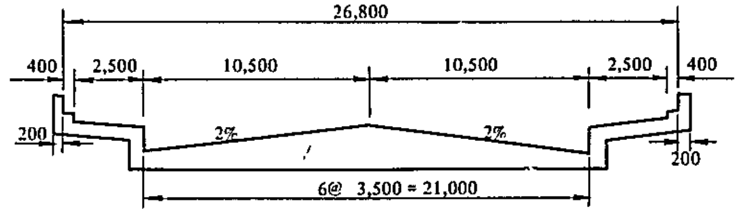
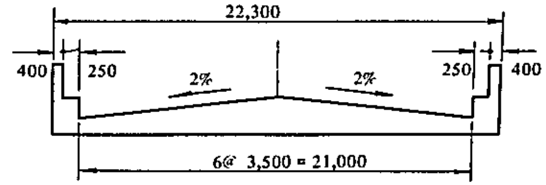


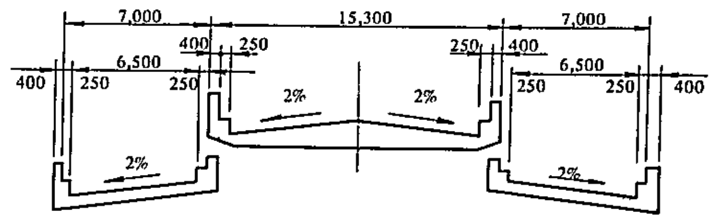
Fig. 3–2–3 WIDTH AND CROSS SLOPE



The Cross Section for the Main Bridge



The Cross Section for the Approach on the Bangkok Side



The Cross Section for the Approach with on –and off–
Ramps on the Thon Buri Side

Fig. 3–2–4 CLEARANCES UNDER THE GIRDER

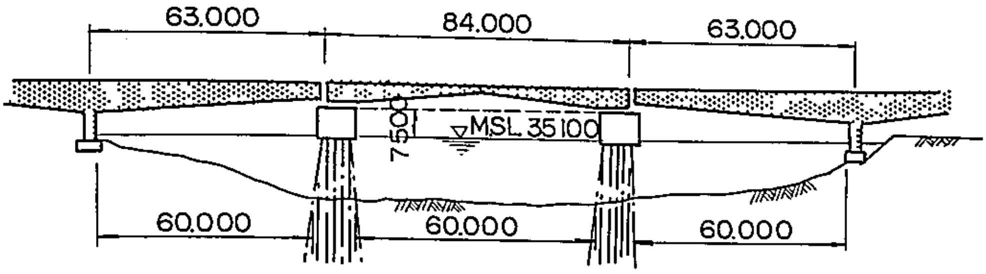
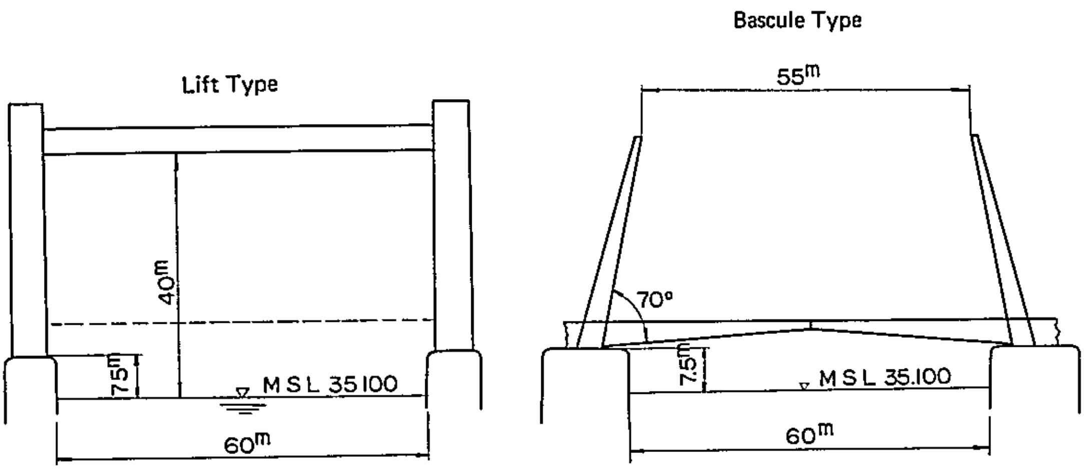


Fig. 3–2–5 CLEARANCES OF MOVABLE BRIDGES UNDER OPERATION



(e) Live Load

The bridge shall be capable of bearing a live load of HS20-44 specified in AASHO. However, the "Reduction of Load Intensity" in AASHO specifications shall not apply.

(f) Other Loads

With the exception of the following loads, the relevant Japanese standards shall apply.

i) Seismic Force

The seismic force and the weight of public utilities shall not be taken into consideration.

ii) Wind Load

$$W = \frac{1}{2} \cdot C \cdot \rho \cdot v^2$$

where, W : wind load (kg/cm^2)
C : coefficient of wind pressure, 1.6 for road bridge
ρ : density of air, normally 0.125 $kg.sec^2/m^4$
v : wind velocity (m/sec)

Wind velocity of 150 km/h for normal condition and 80 km/h during operation.

iii) Temperature Variation

Temperature variation of 10° - 40°C shall be taken into consideration for the steel bridge and ± 5°C for the concrete bridge.

iv) Water Current Force

Water Current force on the piers is calculated for a flow velosity of 10 km/h. Furthermore, an impact load corresponding to a 100 ton static load shall be taken into account at the hight of M.S.L.

(g) Design

Relevant Japanese standards shall apply to all structural details excluding those specified below.

i) With the exception of the movable portion, the roadway shall be paved with 5 cm-thick asphalt concrete, and the sidewalks with 3 cm-thick cement concrete.

ii) The floor of the movable span shall be a solid steel grating with concrete (σ_{28} = 240 kg/m^2), having a thickness of 13 cm.

iii) Prestressed concrete structures shall be constructed by full prestressing.

(h) Materials

All materials shall satisfy JIS and other relevant Japanese standards.

(i) Power Supply

Power to be used for bridge operation shall be AC 3,500 V, 50 Hz, 3ϕ.

3-3 Preliminary Selection of Bridge Types

(1) General

As to the superstructure of the central span, a comparative study of the lift type and the bascule type was made in regard to the initial construction cost and the maintenance expenses, giving priority to the latter. The operating mechanism should be either the sector gear type or the drum winding type in view of the fault-free characteristics and the low maintenance cost of both methods. And it was decided that the floor was to be designed, on a trial basis, by the solid steel grating with concrete which promises longer service and is advantageous in the maintenance of the main girders. However, this floor will increase the total weight of the steel material.

As for the superstructure of the side span, because of the great span length (approx. 60 m) it is justifiable to adopt a steel bridge rather than a P.C. bridge. The steel bridge excels both in safety of erection and in initial cost for such a long span. However, in compliance with the Thai Government's desire to select a structure which incurs the least amount of maintenance cost and which can make full use of locally available meterials, the P.C. structure was decided upon. This, however, has necessitated a substantially long anchor span.

With respect to the structure of the approach span, either the P.C. structure or the R.C. structure shall be employed, depending on the span length and cost.

(2) Superstructure

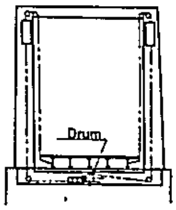
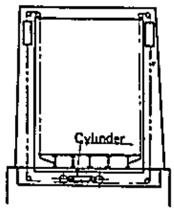
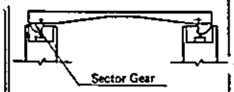
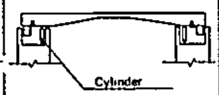
(a) Central Span

i) Operating Mechanism

There are four different mechanisms that can be applied to the operation of the proposed movable bridge. Table 3-3-1 gives a summary of the performance of these mechanisms.

A comparison of the two major operating mechanisms now in use, the gear system and the hydraulic system, discloses that with the former it is much easier to handle and maintain, but at the same time, it is heavier and has a rather complicated mechanism. The latter, which has been remarkably developed in recent years, requires a substantially high technical level in both handling and maintenance, but is lighter, less complicated mechanically, and a little cheaper. Discussions with the Thai Authorities led to the conclusion that the gear system would be adopted because it is easier in both handling and maintenance; and that the Ward-Leonard System would be employed for speed control since it assures smooth speed control and fault-free operation, though somewhat expensive.

Table 3-3-1 Operating Mechanism of Movable Bridge

Item \ Type	Vertical Lift Type		Bascule Type	
	Electromotive Drum Winding Type	Hydraulic Cylinder Type	Electromotive Sector Gear Type	Hydraulic Cylinder Type
				
	Drum	Cylinder	Sector Gear	Cylinder
Openning Speed	Normal :10m/min Emergency: 3m/min	10 m/min 3 m/min	10 m/min 3 m/min	10 m/min 3 m/min
Openning Time	Normal :198 sec Emergency :660 sec	198 sec 660 sec	120 sec/75° 360 sec/75°	120 sec/75° 360 sec/75°
Bascule Angle	/	/	75°	75°
Lift	33.0 m	33.0 m	/	/
Clearance above MSL	40.0 m	40.0 m	/	/
Safety Factor	Machinery : 5 Wire rope : 6 (3 for combined stress)	5 6 (3 for combined stress)	5	5
Location of Control Room	Tower top	Tower top	On the pier	On the pier
Power Source	7,000 V, 50 Hz	7,000 V, 50 Hz	7,000 V, 50 Hz	7,000 V, 50 Hz
Hydraulic Pressure	/	Max. 140 kg/cm^2	/	Max. 140 kg/cm^2
Speed Control	Ward-Leonard System	Hydraulic pump with variable speed	Ward-Leonard System	Hydraulic pump with variable speed
Locking Time	30 sec/cycle	30 sec/cycle	30 sec/cycle	30 sec/cycle
Time for Road Barrier	20 sec/cycle	20 sec/cycle	20 sec/cycle	20 sec/cycle

ii) Floor

The grating or the steel plate deck is employed most commonly for the floor of movable bridges. The grating is often applied with concrete as filling material, and this is called the solid steel grating with concrete. Table 3-3-2 gives a comparative study of various floor types including these two major types. Discussions with the Thai Authorities on these two types resulted in the adoption of the solid grating, in view of the smooth riding comfort and the easy maintenance it assures, although the construction cost is rather high.

iii) Main Girder

The structure of the main girder depends on the floor system. The conceivable floor systems are the reinforced concrete slab or the grating and the steel plate deck. The former includes four different types as illustrated below with their respective characteristics. In the case of the latter type, two structures are conceivable, i.e., one-box girder (or trapezoidal-box girder) and two or three-box girders with cross beams. The type of three-box girders with solid grating was adopted since it excels both in appearance and rigidity and is also advisable for economical reasons.

iv) Other Structures

For the towers of the lift bridge, the truss-type structure covered with curtain plates has been adopted.

v) Erection Method

Considering the large river depth and the heavy waterway traffic at the construction site, the bridge has been planned to be erected by means of a large floating crane and barges without bents. This method calls for a substantially large assembly yard with a wharf for barges near the site. Studies on the erection method are given in 3-5-(3) (a).

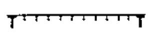
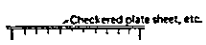
(b) Side Spans

For the selection of the superstructure, a comparative study was made on the following five types illustrated in Fig. 3-3-2.

a) T-rahmen
b) Continuous girder
c) Cantilever girder
d) Simple beam
e) Suspended girder

In view of the frequent passage of ships on the Chao Phraya, it was found in the comparative study that the main girder erection over the river should be executed not by the all staging method but chiefly by the cantilever construction method or by the precast-block method. Furthermore, the length of the anchor span on land of the T-rahmen bridge and the continuous girder bridge was another subject of the study, because it affects the construction method to be applied, the effect of the superstructure on the central pier, as well as the rampway plan.

Table 3-3-2 Floor System

Type	Kind	Weight	Rate of weight (Ratio)	Rate of dead load (Ratio)	Rate of bending moment (Ratio)	Material	Description
A	Reinforced concrete (Ordinary concrete)	0.5 t/m² Thickness: 20 cm	3.33	1.93	1.79	Concrete: 340 m³ Reinforcement:70t	1. Materials are available in Bangkok. 2. Bridge and machinery become uneconomical due to heavy weight of floor slab. 3. Pavement required.
B	Reinforced concrete (Light weight concrete)	0.36 t/m² Thickness: 20 cm	2.40	1.39	1.28	Concrete: 340 m³ Reinforcement:70t	1. Light Weight aggregates are not available in Bangkok. 2. Pavement required.
C	Solid grating (Ordinary concrete)	0.376 t/m² Thickness: 13 cm	2.51	1.46	1.35	Concrete: 240 m³ Grating: 106 t	1. Gratings not available in Bangkok. 2. Pavement required. 3. Forms not required for concreting (forms to be affixed to gratings at shop).
D	Solid grating (Light weight concrete)	0.304 t/m²	2.02	1.17	1 08	Concrete: 240 m³ Steel Grating:106t	1. Gratings and aggregates not available in Bangkok. 2. Pavement required. 3. Forms not required for concreting (forms to be affixed to gratings at shop).
E	Open Grating	Unit weight: 0.15 t/m² Total weight: 220 t Thickness: 15 cm	1.00	1.00	1.00	Steel Grating:200t	1. Gratings not available in Bangkok. 2. Easy repair assured. 3. Superior against wind load (wind load decreases by 70%). 4. Not comfortable and noisy. 5. Pavement not required.
F	Steel plate deck	With asphalt pavement					1. Weak resistance to high temperatures. 2. Pavement work needs pavement equipment. 3. Thin pavement (such as Latex pavement) is preferable, but its maintenance is difficult.
		Without asphalt pavement					1. Partial replacement possible. 2. Surface rather slippery. 3. Field welding required.
							1. Field welding required. 2. Surface rather slippery.

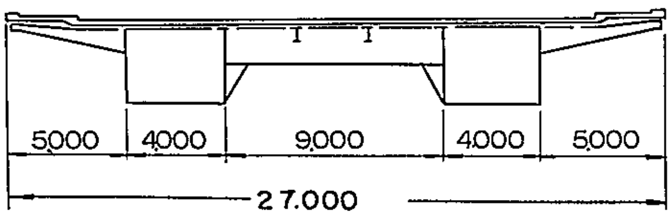
NOTE: 1. *Comparison given above is based on the condition that the intermediate floor beams are set at a spacing of 3 m.*

2. *Rate of dead load means the rate of dead load including the slab weight (to that of open type grating).*

3. *Rate of bending moment means the rate of the overall bending moment caused by the dead load including the slab weight (to that of the open type grating).*

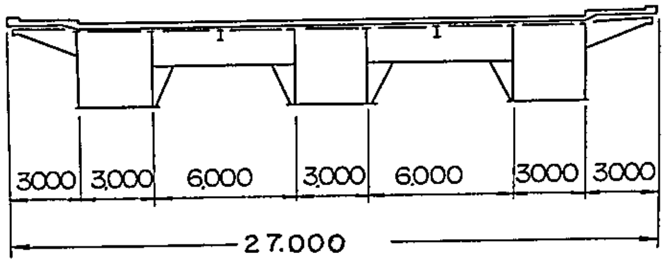
Fig. 3–3–1 COMPARISON OF MAIN GIRDER STRUCTURES

Two-Box Girder



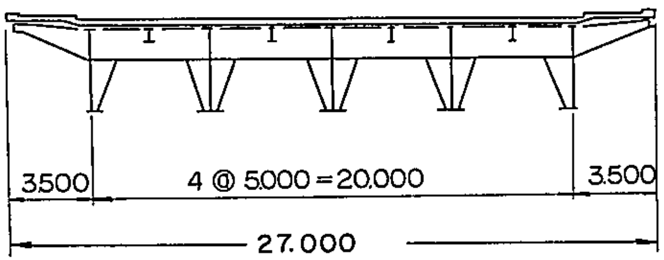
Fabrication more difficult than the plate girder type

Three-Box Girder



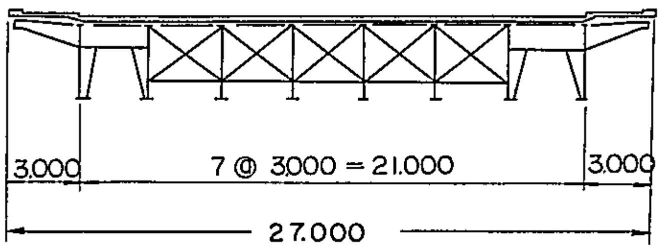
Fabrication more difficult than the plate girder type

Five-Plate Girder



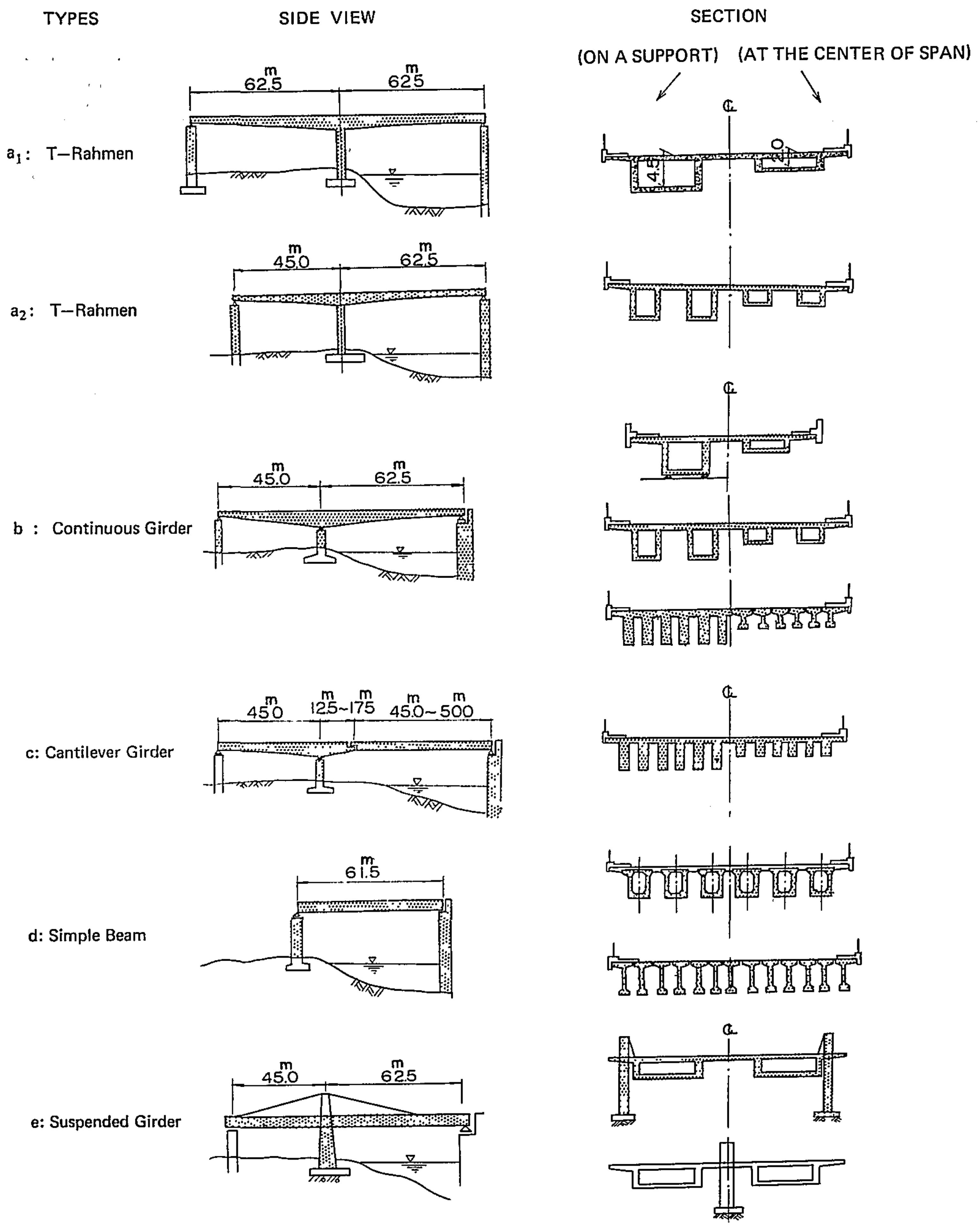
Fabrication easier than the box girder type

Eight-Plate Girder



Fabrication easier than the box girder type

Fig. 3–3–2 COMPARISON BETWEEN DIFFERENT BRIDGE TYPES OF SIDE SPAN SUPERSTRUCTURES



Structural characteristics and contruction methods of each of the above five types are introduced below.

Type a: T-Rahmen (a_1 and a_2 in Fig. 3-3-2)

In this type, the central pier is rigidly connected with the main girder. Type a_1 is for the purpose of making the spans on land and over the river symmetrical to the pier in order to alleviate the bending moment which is induced on the central pier due to the dead load. In contrast to type a_1, type a_2 allows a large bending moment to be induced on the central pier because of the non-symmetrical span arrangement. Hence, piers must be larger in structure, but the span length on land need not be so long as required in type a_1.

As for the construction method, the staging method should be adopted on land, and the cantilever method over the river. If the cast-in-place method is to be applied to the entire river section, using a movable scaffolding, the two-box girder type would be most economical. However, if the application of the precast-block method is demanded, because of the limited capacity of erection equipment, it is suitable to use multi-box main girders, which consequently require more steel materials for reinforcing the block joints than in the case of the cast-in-place method. However, it assures quicker construction and serves to shorten the overall construction period.

Type b: Continuous Girders (b in Fig. 3-3-2)

In this type the continuous main girder is supported by bearing shoes on a pier, whereby no bending moment is imposed on the central pier. However, the necessity for large bearing shoes incurs a higher construction cost than for Type a.

As in the case of Type a, the staging method is to be employed on land, and the cast-in-place method using a movable scaffolding or the precast-block method should be applied over the river section. The section of the main girder will vary as shown in Fig. 3-3-2 depending on the construction method employed.

Type c: Cantilever Girder (c in Fig. 3-3-2)

The girders constructed by this method are statically determinate structures which are completely free from the stress due to differential settlements of the piers.

As for the erection method, the span on land and the beam overhanging the river should be constructed by the cast-in-place method using a staging, while the suspended girder is to be constructed by the precast beams. Since the span over the river is composed of precast beams, its construction is easier and requires less time than in the cases of Types a and b. The drawback in this plan is that the heavy weight of precast beams requires special erection equipment and further invites the difficulty in transportation. Another drawback is the need for a large number of expansion joints, which is not desirable for maintenance.

Type d: Simple Beam (d in Fig. 3-3-2)

This type is advangeous in that the span on land can be independently designed so as to have the most economical span length and structure. Furthermore, like Type c, it is free from the adverse effects due to differential settlement. However, the non-applicability of the all-staging method makes the main girder erection extremely difficult. The section of the main girder differs depending on whether the cast-in-place method using the erection girder is adopted or the single precast beam is used. In either case, the section becomes inevitably larger and more materials are needed than in the aforesaid two types.

Type e: Suspended Girders (e in Fig. 3-3-2)

In this type, the main girder is to be suspended by cables from the post which is set up on the central pier.

This type permits the cables to serve as the falsework for the main girder erection. However, it involves the extreme difficulty in adjusting the stresses in the cables.

As a result of a comparative study on the abovementioned five types with special reference to materials, simplicity of construction and appearance, four types were selected for the discussion with the Thai Authorities. These four types are: the T-rahmen with equal spans, the continuous girder with non-equal spans, the cantilever girder, and the simple beam.

The followings are the conclusion of the preliminary discussion:

i) Both the continuous and the T-rahmen types shall be designed for comparison to determine the economically preferable one including the cost of the substructure.

ii) The span lengths shall be unequal in both types.

iii) The main girder shall be the box girder, and the its depth of the girder shall be variable so that it looks continuous with the movable span.

iv) The erection shall be executed by the all-staging method on land, and by the cast-in-place method using the movable scaffolding over the river.

The abovementioned conditions served as the basis upon which the preliminary design was prepared for the comparative study. The results of the comparative study are given in 3-4-(3).

(c) Approaches

The superstructure of the approach was planned to be either of prestressed concrete or reinforced concrete, while its span length was designed to minimize the overall construction cost. Furthermore, considering the extremely soft soil observed near the construction site, the maximum embankment height was set at 2.0 m. Consequently, the approaches were designed as elevated structures where an embankment of higher than 2.0 m was required.

As for the type of superstructure, the following studies were made:

i) P.C. precast simple beam

ii) R.C. continuous hollow slab

iii) P.C. I-shaped composite beam

iv) P.C. T-shaped simple beam

v) P.C. continuous beam

Since piles of 20–25 m long are necessary for the pier foundation, the economical span length will be about 25 m.

After the discussions, it was agreed that the T-shaped P.C. simple beam would be adoped because it would need the least amount of field work and a short construction period. As for the span length, it was determined that the clear span should be 30 m at the intersections across Charoen Krung Rd. and Charoen Nakhon Rd., and about 25 m in all other sections.

(3) Substructure

(a) Central Span

The caisson foundation and the pile foundation are the primary methods conceivable for the central span. In the case of a large structure such as the central span of the proposed Sathorn Bridge, conventionally the caisson foundation would be adopted. However, noting the remarkable progress made in recent years in the piling work for which large piles, measuring 1 m in diameter and 60 m in length, are now widely used, due consideration should be given to the possibility of employing the pile foundation.

Among a number of methods currently used for the pile foundation, the reverse-circulation method and the steel pile method are the major ones. At the discussions held with the Thai Authorities, however, the latter method was discarded.

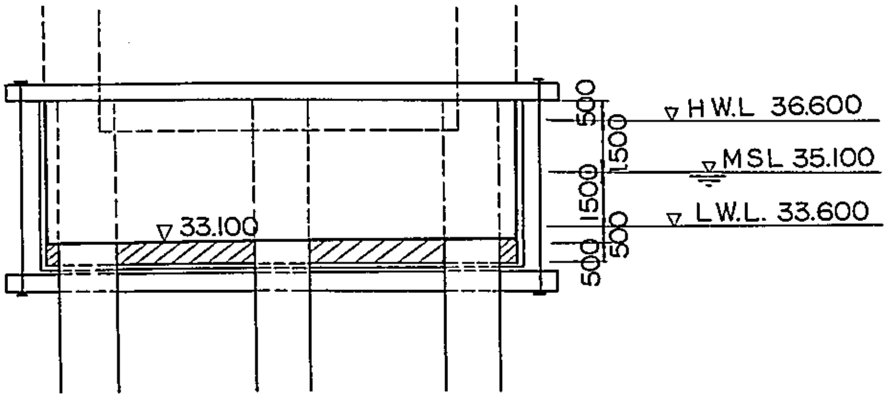
The reverse-circulation method, a type of cast-in-place method, uses piles measuring 0.75–1.5m in diameter. Since the batter piles cannot be used in this method, the horizontal force due to current pressure has to be resisted by the vertical piles alone. Preferably such vertical piles should be as large in diameter as possible. Therefore, it has been decided to employ piles of 1.5 m diameter, the largest now available for the reserse-circulation method.

One of the major problems involved in the pile foundation is how to connect the piles with the pier footing. Connection of the pile with the pier footing is usually carried out under dry conditions, which is rather difficult to realize in the case of the central span of this bridge. Fig. 3-3-3 shows the method devised by the Japanese Survey Team to make the piles and pier footing dry, but it is applicable only if the bottom plate of pier is within 3 m under the water.

In contrast to the above method, the caisson foundation excels in stability and is generally accepted as one of the most advisable methods. However, it has its own demerits. For instance, it incurs a higher cost, needs a longer construction period, and in particular, invites noticeable difficulties if the work has to be done 20 m under water.

The sinking of the caisson can be conducted in two different ways, i.e., the pneumatic method and the open method. Of these two methods, the former was adopted because of its higher working accuracy. To build caissons, there are two methods, the artificial island method and the floating method. The former is not practical for the central span because the river is as deep as 20 m at the site. The alternative method, i.e., the floating method, can be applied in

Fig. 3–3–3 THE METHOD TO CONNECT THE PILES WITH PIER FOOTING



two different ways. In one way, a floating caisson of reinforced concrete is built from the beginning, and in the other way, a steel floating caisson is towed to the position of the pier where it is sunk by pouring concrete on it to build up its upper portion.

A floating caisson made of reinforced concrete presents a number of problems due to its weight. First, the foundation of the dock yard, where the caisson is to be built, has to be made quite firm, moreover, launching the completed caisson into the water is a difficult job, and finally because of the depth of the caisson it is rather expensive to provide with the necessary towing channel. Accordingly, unless a suitable dock yard is available near the construction site, the steel floating caisson is far more advantageous.

In this report, therefore, a comparative study was made on the pile foundation by the reverse-circulation method and the caisson foundation for application to a lift bridge with pier footings 3 m under water. On the other hand, the caisson foundation alone was studied for the bascule bridge which would need pier footings exceeding 3 m below the water. The caisson referred above is the floating caisson made of steel plate.

The third-stratum was selected as the bearing stratum for the caisson foundation, while the fifth stratum was decided on for the pile foundation in view of the necessity to provide as large a horizontal and vertical resistance as possible.

The penetration depth of the caisson into the third stratum will be more than 5 m to provide protection from scouring liable to take place after the completion of the bridge.

(b) Side Spans

The description given in the foregoing pages for the central span is true also for the side spans. Studies and reviews needed for the side span foundation are consequently identical in nature to those for the central span. However, the artificial island method is adoptable for the execution, because the river is not so deep at the pier sites of the side spans as of the central span.

The open excavation method is most suitable for the sinking operation.

(c) Approach

The substructure of the approach is desired to be designed so that the P.C. or R.C. piles available and standardized in Thailand can be used, and construction of piers in the Khlong Sathorn will not impede its function. The design and construction schedule should be prepared to assure the function of the canals during construction. A comparison between P.C. piles and R.C. piles, revealed that the former were preferable.

3-4 Comparative Study by Preliminary Designs

(1) Assumed Conditions in Cost Estimation

Figs. 3-4-1 and 3-4-2 respectively illustrate the general view of the bascule bridge and the lift bridge, both designed in accordance with the Design Specifications given in 3-2-(3).

The cost estimation was conducted with due regard to the following circumstances.

The unit cost employed in the estimation is the average unit cost applied in Japan and Thailand during 1969. Customs duty and business taxes in Thailand are taken into account.

The cost of electrical and mechanical equipment is estimated on the basis of the specifications given in Table 3-4-1.

The cost of the assembly yard is not included in the cost estimation.

It was assumed that the movable span would be manufactured in Japan and that all the parts of the span would be shipped from Japan to Bangkok.

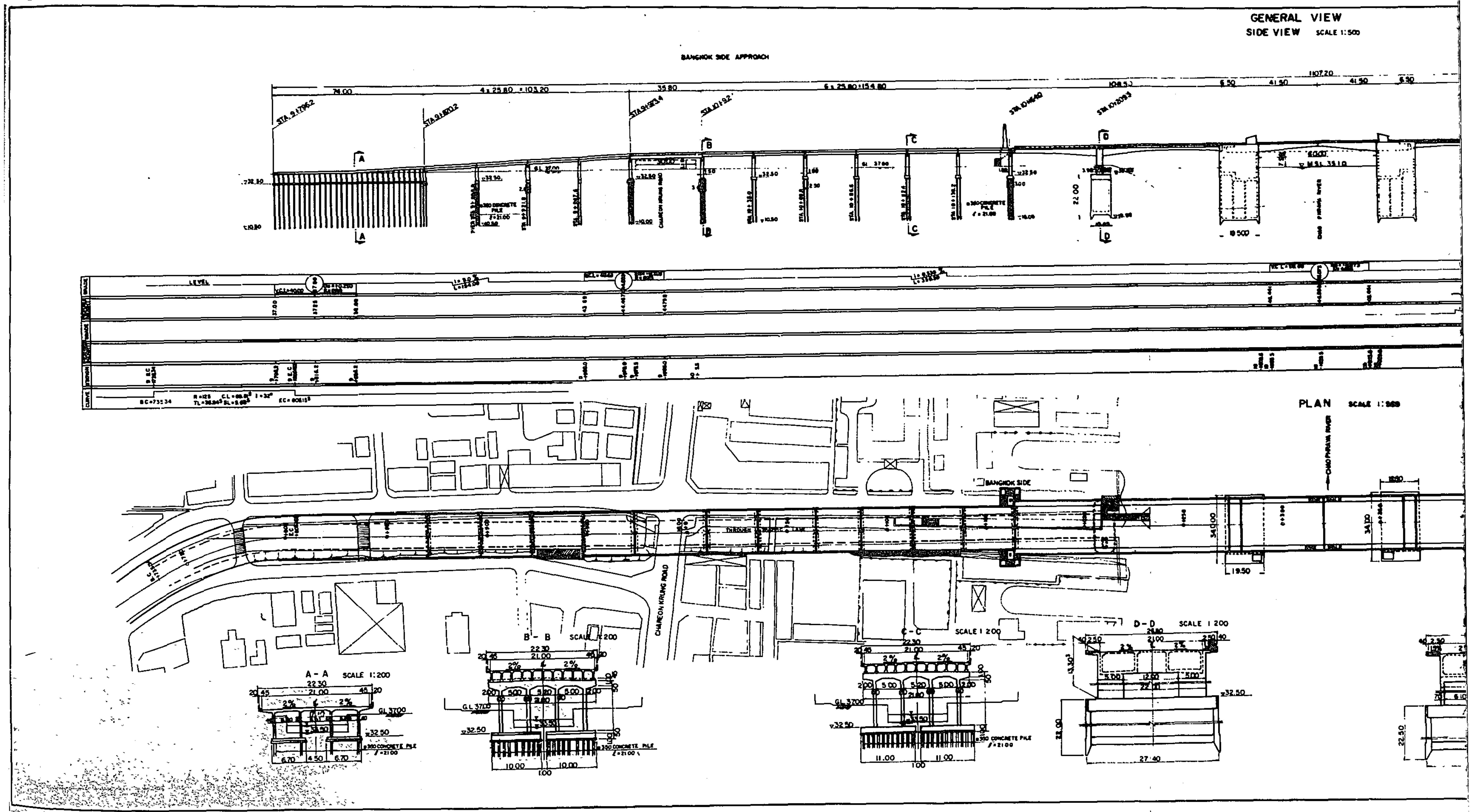
The cast-in-place method was used to place concrete for the solid grating. About 3,500 tons of steel materials needed for the counter weight of the movable bridge as well as concrete for filling are presumably available in Thailand.

The caisson foundation was used for both the central and side spans, with the cast-in-place concrete pile method using the reverse circulation drill, taken as an alternative method for comparison. Machines needed for the steel floating caisson and for the pneumatic caisson method are assumably to be imported.

The cost estimation for the side span foundation is conducted on the assumption that the central span and the side span will have the same type of foundation because the construction of two different kinds of foundations is not desirable because of the higher cost, and the necessity of importing machines for both works as well as the need to employ two groups of technicians.

It has also been assumed that all the concrete for the cast-in-place will be ready-mixed concrete, and that steel reinforcement for the P.C. as well as the materials for the movable scaffolding needed for the P.C. girder construction will be manufactured in Japan and imported to the construction site.

Fig. 3-4-1 GENERAL VIEW OF THE BASCULE TYPE FOR CENTRAL SPAN



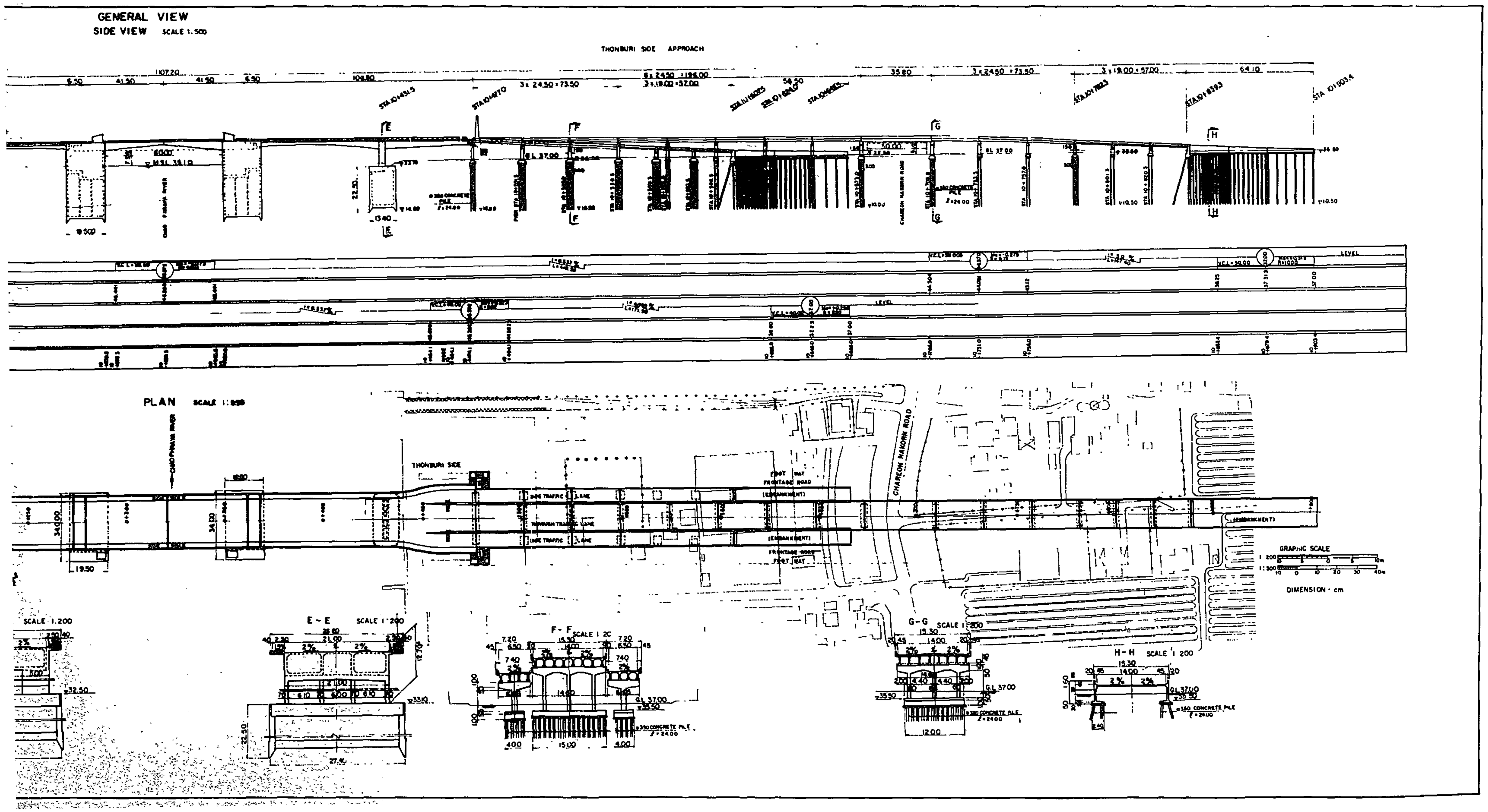
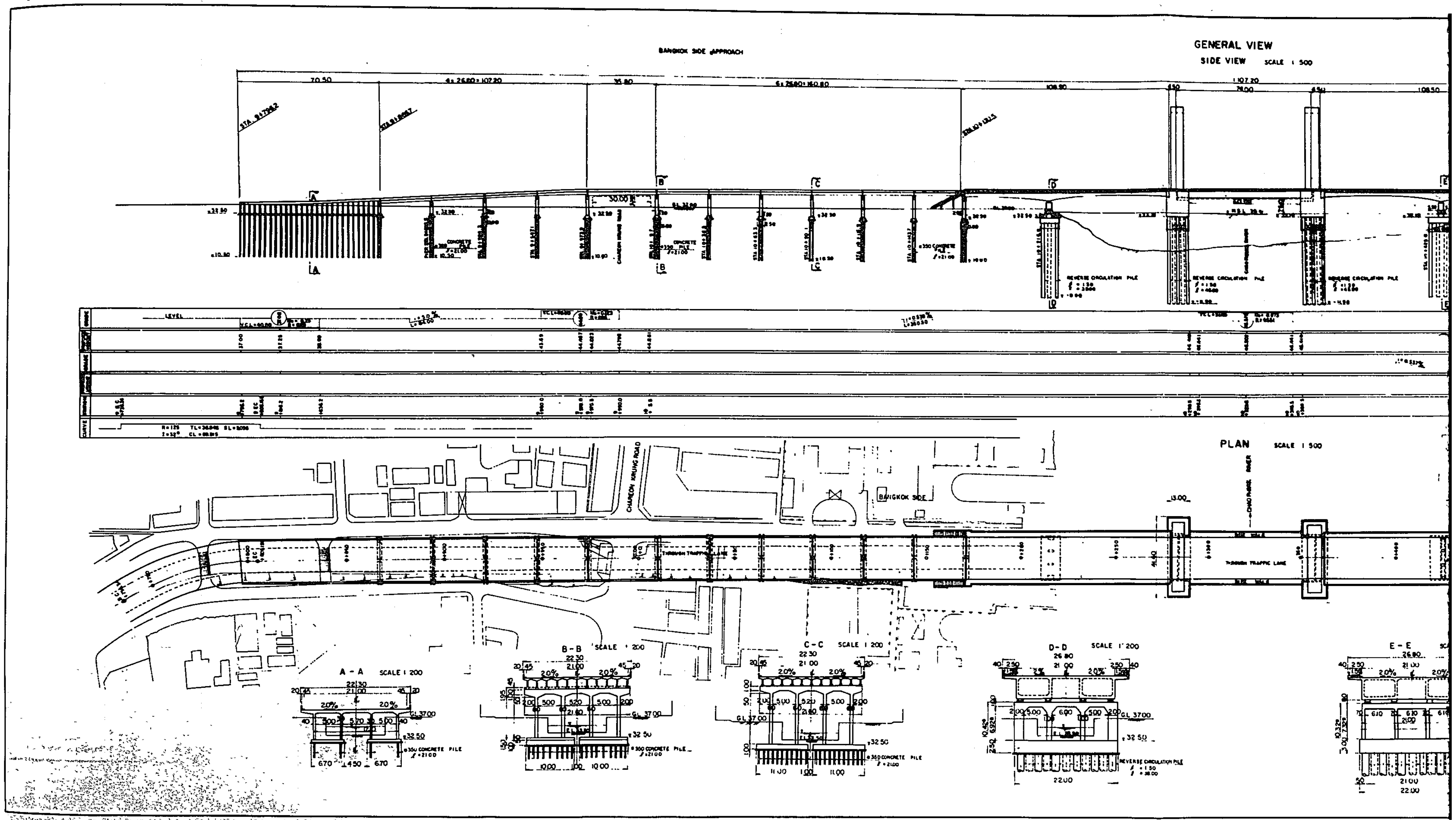

GENERAL VIEW
SIDE VIEW SCALE 1:500
THONBURI SIDE APPROACH
PLAN
THONBURI SIDE
CHAREON NAKORN ROAD
SIDE TRAFFIC LANE
THROUGH TRAFFIC LANE
FRONTAGE ROAD
FOOT WAY
(EMBANKMENT)
GRAPHIC SCALE
DIMENSION : cm
E - E SCALE 1:200
F - F
G - G
H - H SCALE 1:200
SCALE 1:200
CONCRETE PILE
LEVEL

Fig. 3-4-2 GENERAL VIEW OF THE LIFT TYPE FOR CENTRAL SPAN



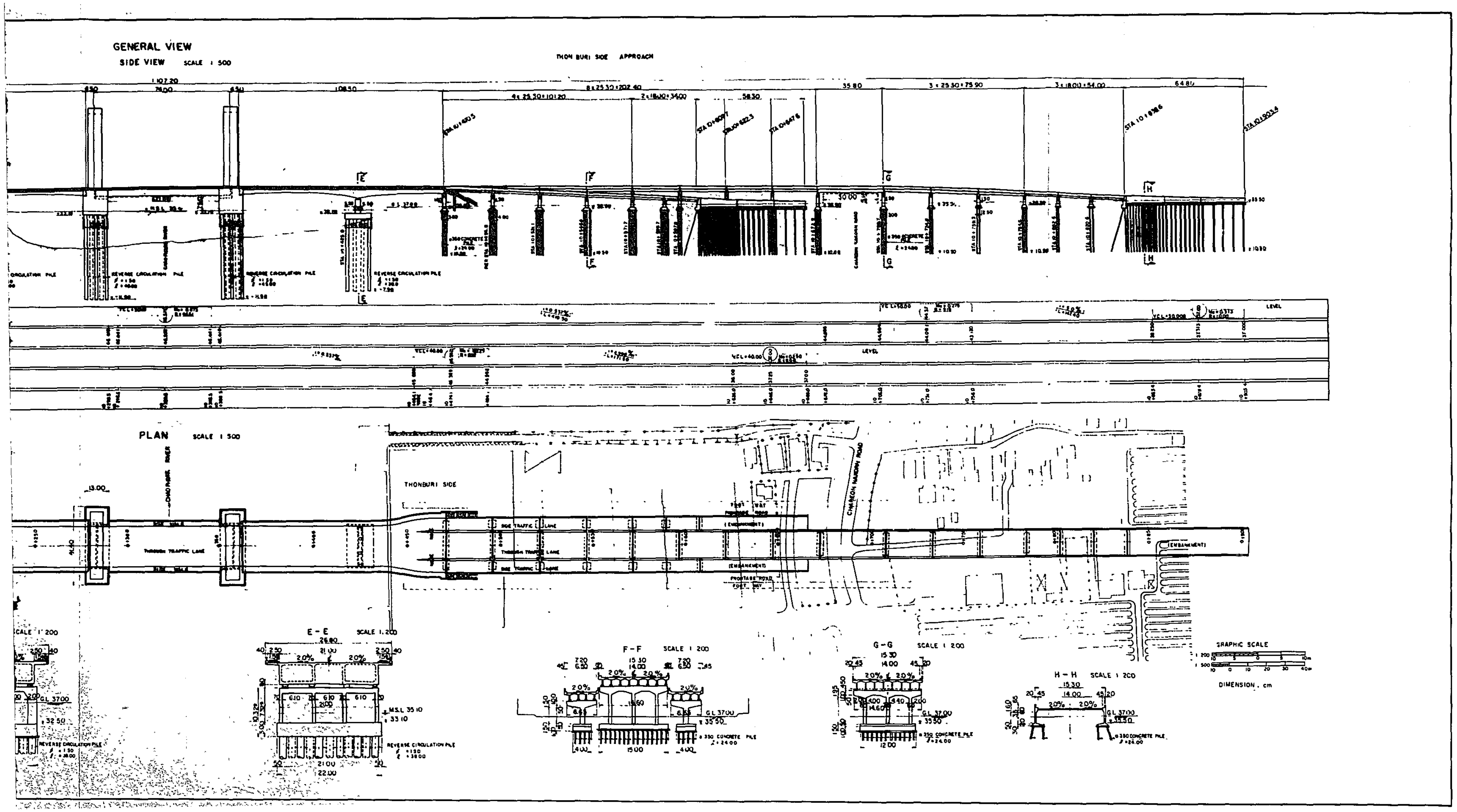

GENERAL VIEW
SIDE VIEW SCALE 1:500
THON BURI SIDE APPROACH
PLAN SCALE 1:500
THONBURI SIDE
THROUGH TRAFFIC LANE
SIDE TRAFFIC LANE
(EMBANKMENT)
E - E SCALE 1:200
F - F SCALE 1:200
G - G SCALE 1:200
H - H SCALE 1:200
REVERSE CIRCULATION PILE
GRAPHIC SCALE
DIMENSION, cm

Table 3-4-1 Specifications of Electrical Machines and Equipment for Central Span

Item \ Type	Lift Type (Electromotive Drum Winding Type)	Bascule Type (Electromotive Sector Gear Type)
a) Electrical Equipment		
1. Standards Applied	JIS (Japanese Industrial Standard)	Ditto
	JEM (Japan Electric Machine Industry Association)	Ditto
	JEC (Japanese Electrotechnical Committee)	Ditto
2. Power Source	AC, 3,500 V, 50 Hz, 3ϕ, 3W	Ditto
	Motor circuit : AC 440V, 50 Hz, 3ϕ, 3W	Ditto
	DC 440V, – –, 3W	Ditto
	Control circuit : AC 220V, 50 Hz, 1ϕ, 2W	Ditto
	DC 110V, – –, 2W	Ditto
	Lighting circuit : AC 220V, 50 Hz, 1ϕ, 2W	Ditto
3. Additional Facilities (Not included in the initial scope of supply)	1) Feeder line to incoming panel (Incoming panel to be installed inside the movable bridge pier)	Ditto
	2) Lighting equipment other than those for movable bridge.	Ditto
b) Mechanical Facilities	Counterweight	Ditto
	Wire rope and sheaves for counterweight	Trunnions
	Lifting wire rope	Adjustable shoe
	Hoist	Ditto
	Counterweight locking device	Shock absorber
	Counterweight guide	Locking device
	Shock absorber	Maintenance hoist crane and hydraulic jack (for adjustment of trunnions)
	Centering block	–
	Maintenance hoist crane and hydraulic jack	–
	Road barrier	Ditto
	Tower and stairs	–
c) Electrical Facilities	High-voltage switch gear	Ditto
	Transformer	Ditto
	DC motor generator	Ditto
	Auxiliary generator	Ditto
	Battery and charger	Ditto
	DC main drive motor	Ditto
	DC control panel	Ditto
	Low-voltage switch gear	Ditto
	Control desk	Ditto
	Lifting equipment	Ditto
	Signal and warning devices	Ditto
	Broadcasting equipment	Ditto
	Anemometers and wind direction indicators	Ditto
	Industrial TV	Ditto
	Transceiver	Ditto
	Private telephone	Ditto
	Ventilators	Ditto
	Elevator	Spare parts
	Spare parts	Wiring and piping materials
d) Control Room (Inclusive of office)	Floor : Steel plate floor w/ plastic tiles	Floor : Concrete slab
	Walls : Asbestos walls finished w/ sandwich panel	Walls : Concrete walls

(2) Central Span

The preliminary designs of the superstructures, in accordance with the aforesaid design specifications, are shown in Fig. 3-4-3 (bascule type) and Fig. 3-4-5 (lift type). The substructures designed in compliance with the same conditions are shown in Figs. 3-4-7 and 3-4-9.

The comparison of costs between these two types indicates, as shown in Table 3-4-2, that the bascule type is preferable to the lift type. Rough estimates of materials required for the two types are as shown in Tables 3-4-3 and 3-4-4. As clearly shown in these tables, the total weight of the materials needed for the steel structures of the bridge and the tower is about 30% less in the bascule type than in the lift type.

The installation cost of the mechanical and electrical equipment is practically the same for the two types, but the bascule type has a lower maintenance cost since its operation requires smaller output and shorter time.

Table 3-4-2 Cost Comparison for Central Span
(Including super and substructure)

(Unit: ฿1,000)

Type / Cost	Bascule Type	Lift Type	
		Caisson Foundation	Pile Foundation
Superstructure	127,600	147,800	147,800
Substructure	53,200	53,700	44,100
Total	180,800	201,500	191,900

(3) Side Spans

The results of the comparative study on the T-rahmen and the continuous girder are as illustrated in Figs. 3-4-10 and 3-4-11.

In comparing the cost of the two types (Table 3-4-6) it is clear that in the superstructure the T-rahmen is less costly and in the substructure the pile foundation is a little cheaper than the caisson foundation. It must be added here though that the figures shown in Table 3-4-6 have been obtained on the assumption that the same type of foundation work would be adopted for the four piers in the river. Therefore, if the caisson foundation is employed for the central span and the pile foundation for the side span, the cost of the pile foundation will become higher than is indicated in the said table, thus making the caisson foundation economically more justifiable. As already explained, the central span should preferably be of the bascule type, and the pile foundation cannot be employed for this type. This leads to the conclusion that the T-rahmen with the caisson foundation should be adopted for the side spans for economical reasons.

Fig. 3–4–3 GENERAL VIEW OF CENTRAL SPAN (BASCULE TYPE)

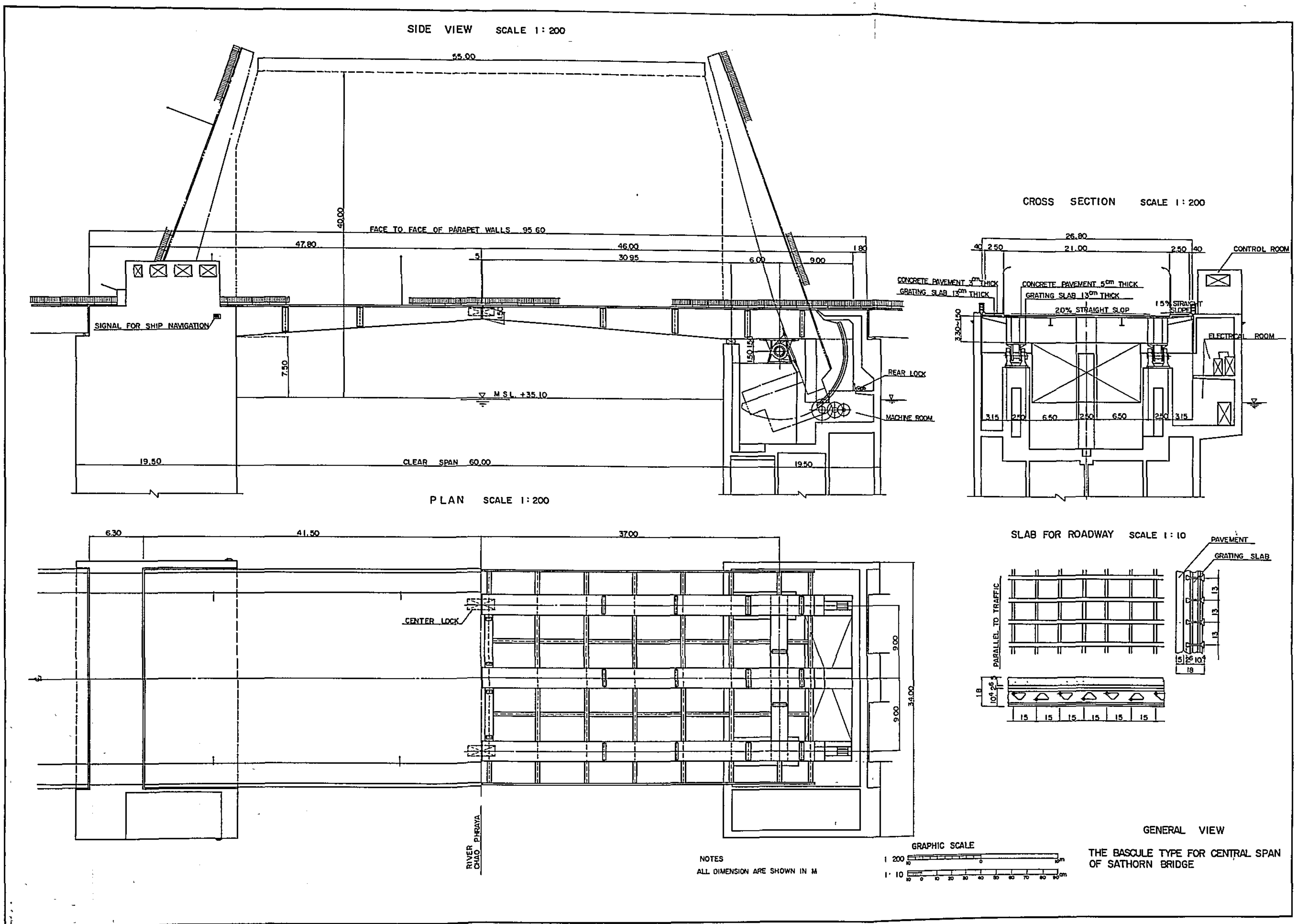
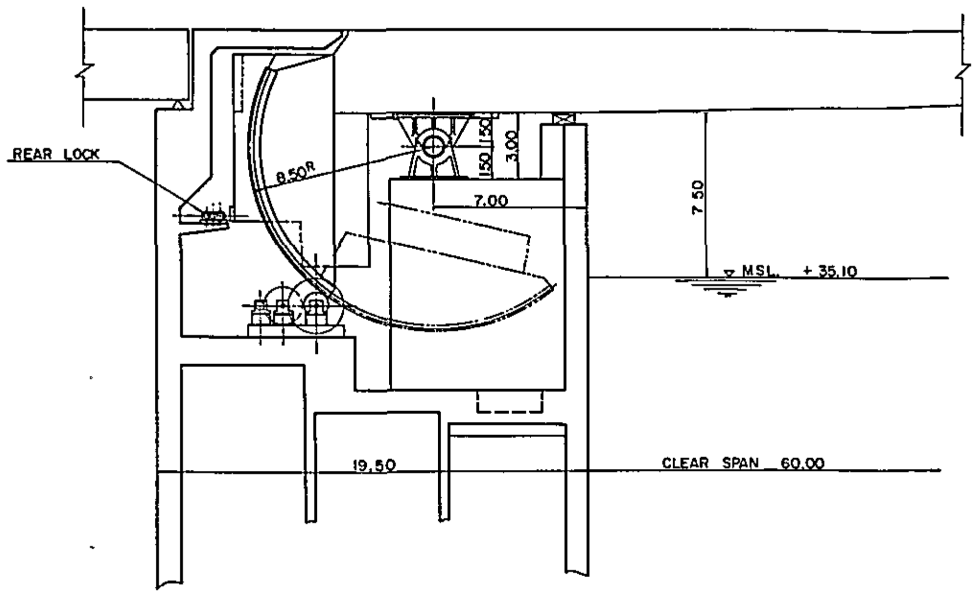
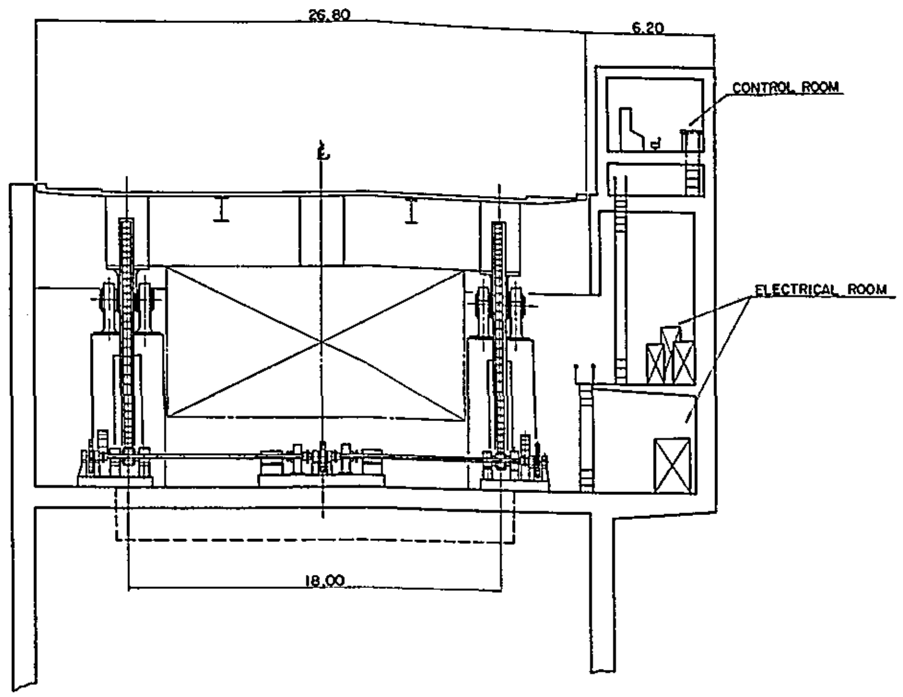


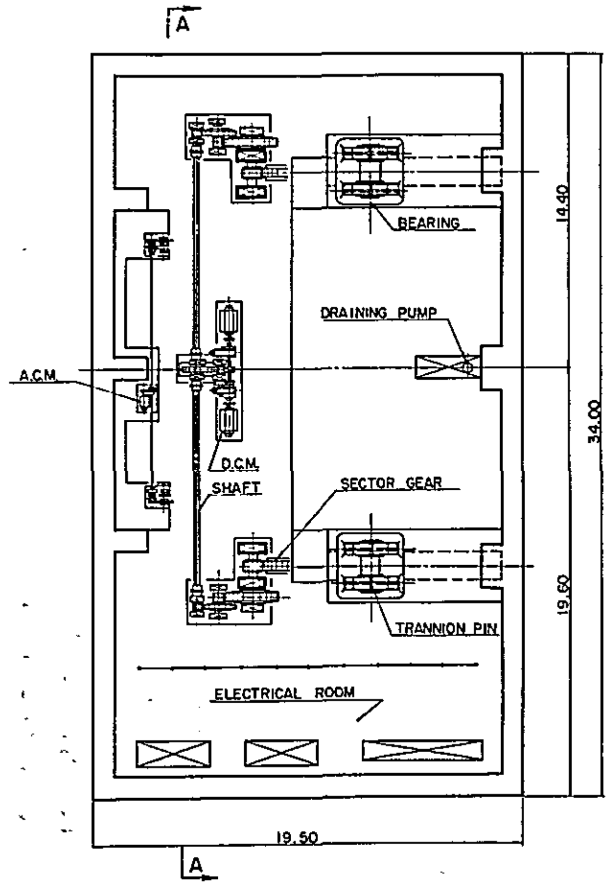
Fig. 3-4-4 ARRANGEMENT OF MECHANICAL EQUIPMENT (BASCULE TYPE)

ELEVATION SCALE 1:150



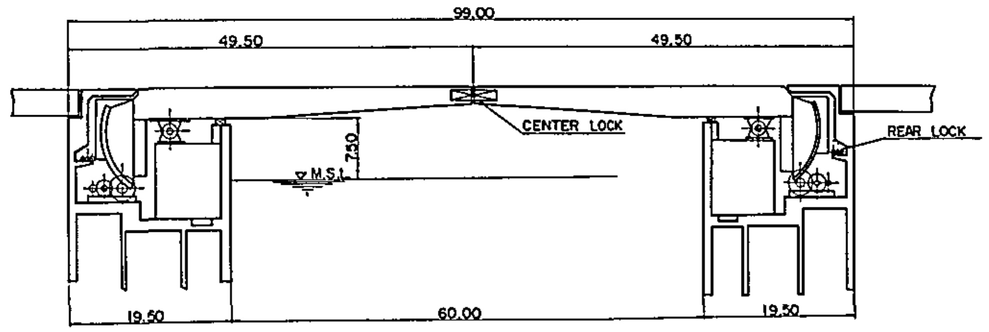


SECTION A - A SCALE 1:150



PLAN SCALE 1:150

GENERAL ASSEMBLY SCALE 1:400



SPECIFICATION

TYPE OF BRIDGE	BASCULE
TYPE	ELECTRICALLY OPERATED TWO SECTOR GEARS TYPE WITH COUNTER WEIGHT SYSTEM
OPENING SPEED	NORMAL TIME $120^{SEC}/70°$ EMERGENCY TIME $360^{SEC}/70°$
OPENING WIND PRESSURE	$48.4^{KG}/M^2$ (SPEED OF WIND $22^{M}/SEC$)
SPEED CONTROL SYSTEM	WARD LEONARD SYSTEM
OPERATING METHOD	REMOTE CONTROL

NOTES
ALL DIMENSION ARE SHOWN IN M

GRAPHIC SCALE

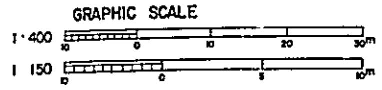


Fig. 3-4-5 GENERAL VIEW OF CENTRAL SPAN (LIFT TYPE)

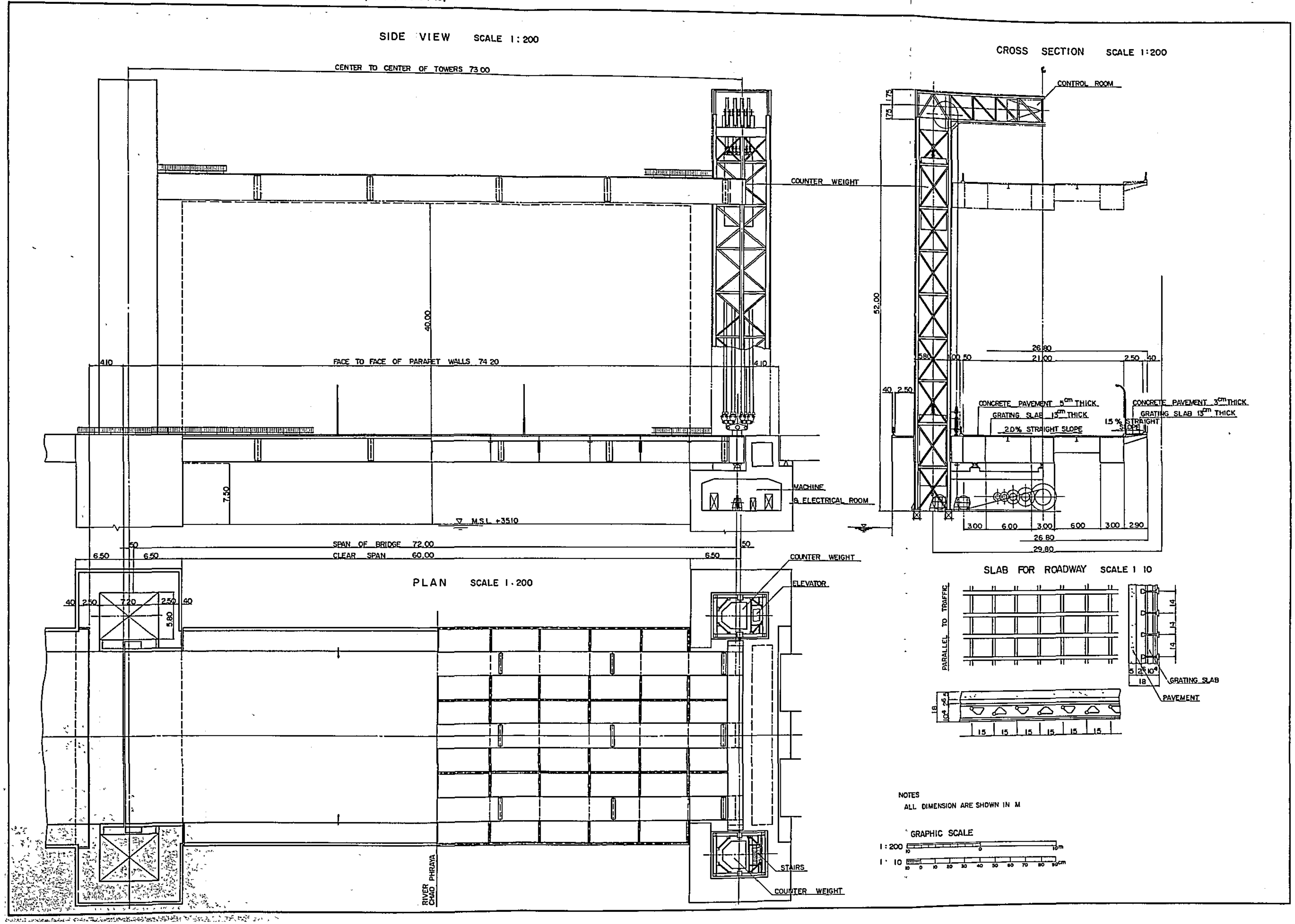
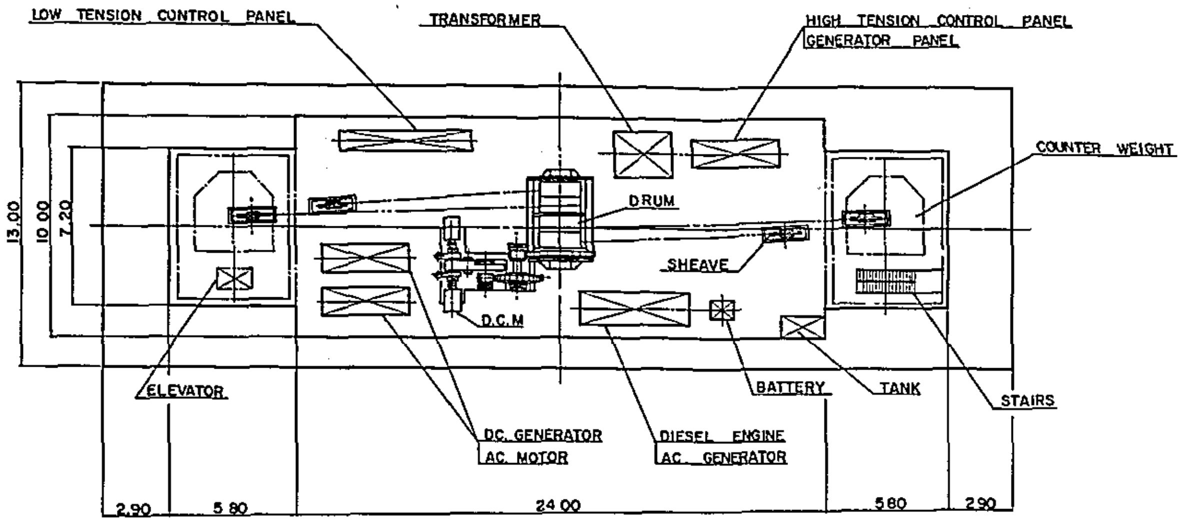
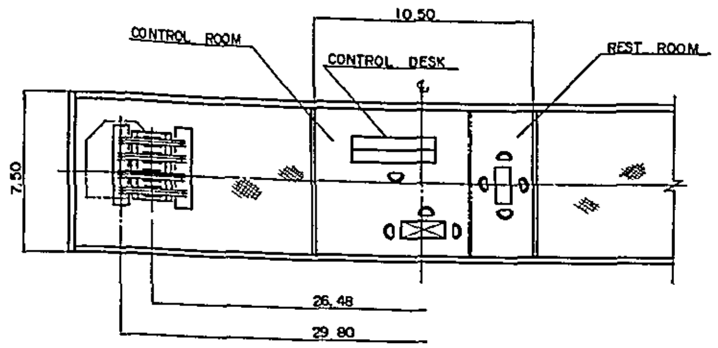


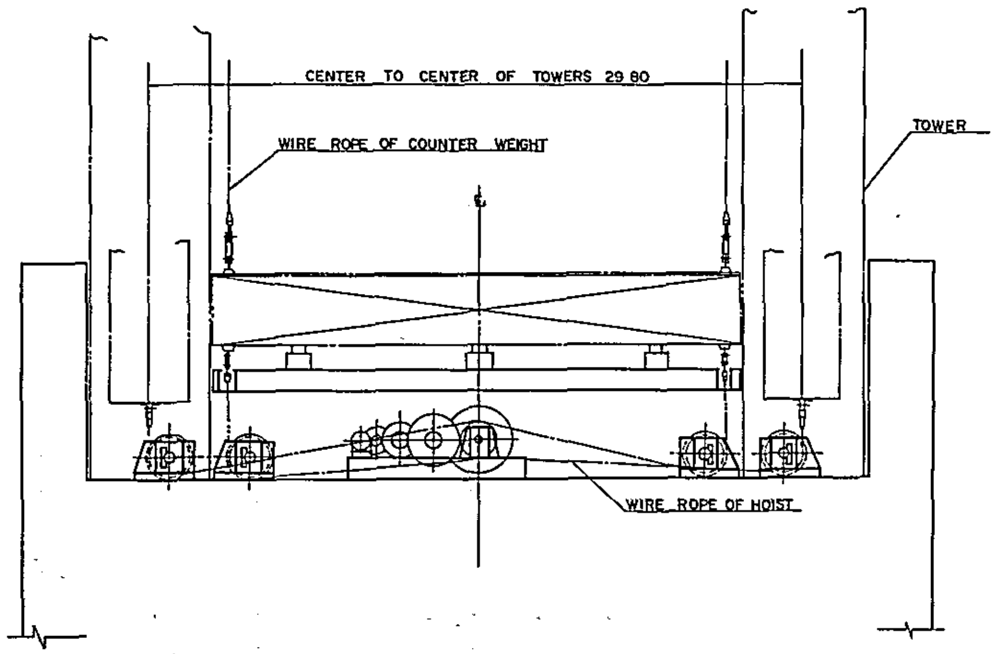
Fig. 3–4–6 ARRANGEMENT OF MECHANICAL EQUIPMENT (LIFT TYPE)



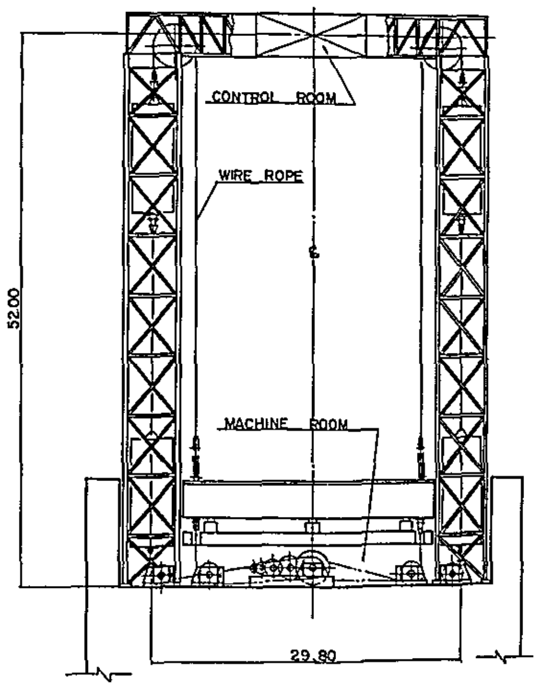
PLAN SCALE 1 : 150



PLAN FOR CONTROL ROOM SCALE 1 : 150



ELEVATION SCALE 1 : 150



GENERAL ASSEMBLY
SCALE 1 : 300

SPECIFICATION

TYPE OF BRIDGE	LIFT
TYPE	ELECTRICALLY OPERATED SINGLE DRUM WINDING TYPE WITH COUNTER WEIGHT SYSTEM
LIFTING SPEED	NORMAL TIME 10 M/MIN EMERGENCY TIME 3 M/MIN
LIFTING WIND PRESSURE	48.4 KG/M2 (SPEED OF WIND 22 M/SEC)
SPEED CONTROL SYSTEM	WARD LEONARD SYSTEM
OPERATING METHOD	REMOTE CONTROL

NOTES
ALL DIMENSION ARE SHOWN IN M

GRAPHIC SCALE

Fig. 3–4–7 CAISSON FOUNDATION FOR BASCULE TYPE (CENTRAL SPAN)

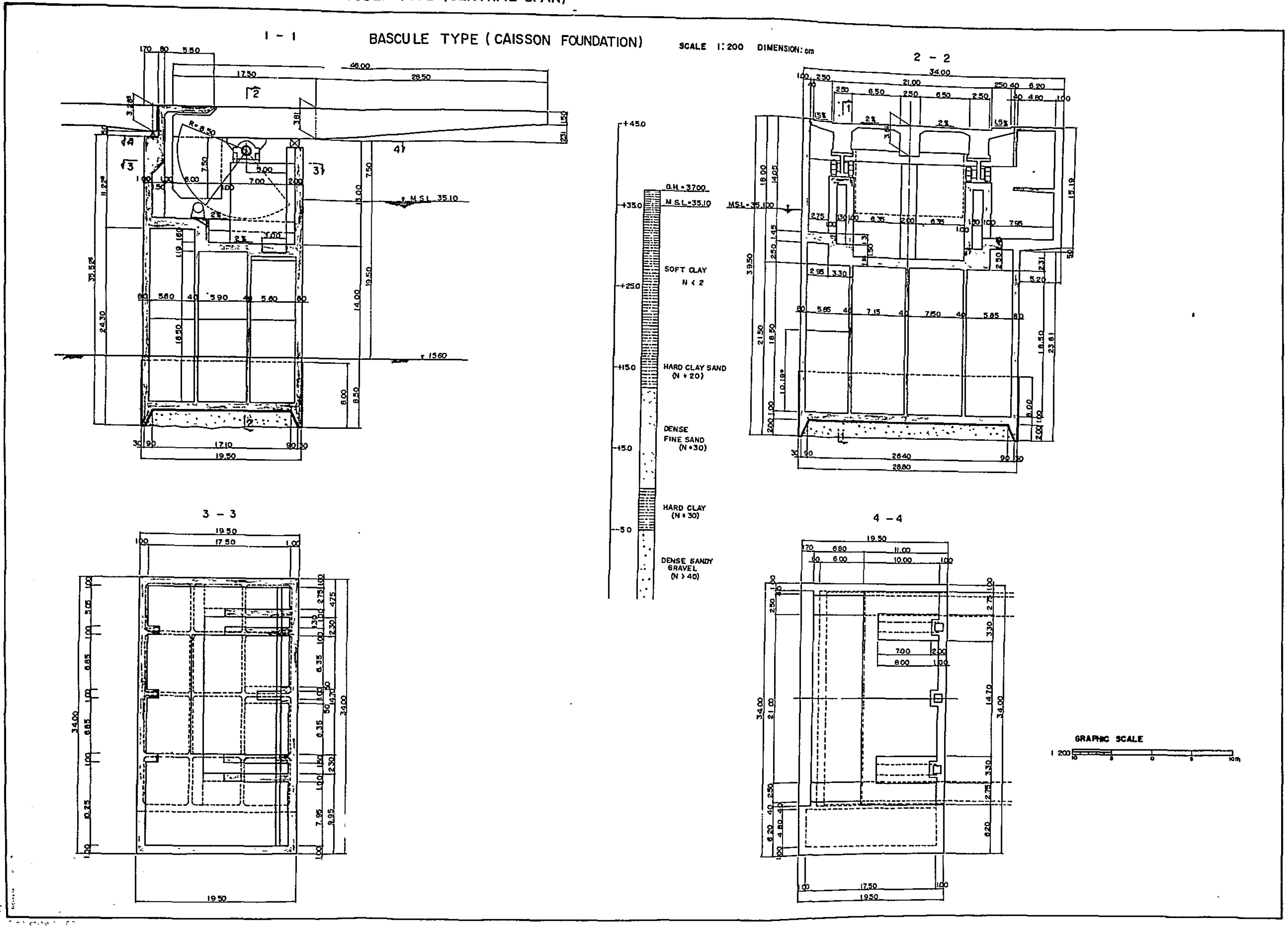


Fig. 3-4-8 CAISSON FOUNDATION FOR LIFT TYPE (CENTRAL SPAN)

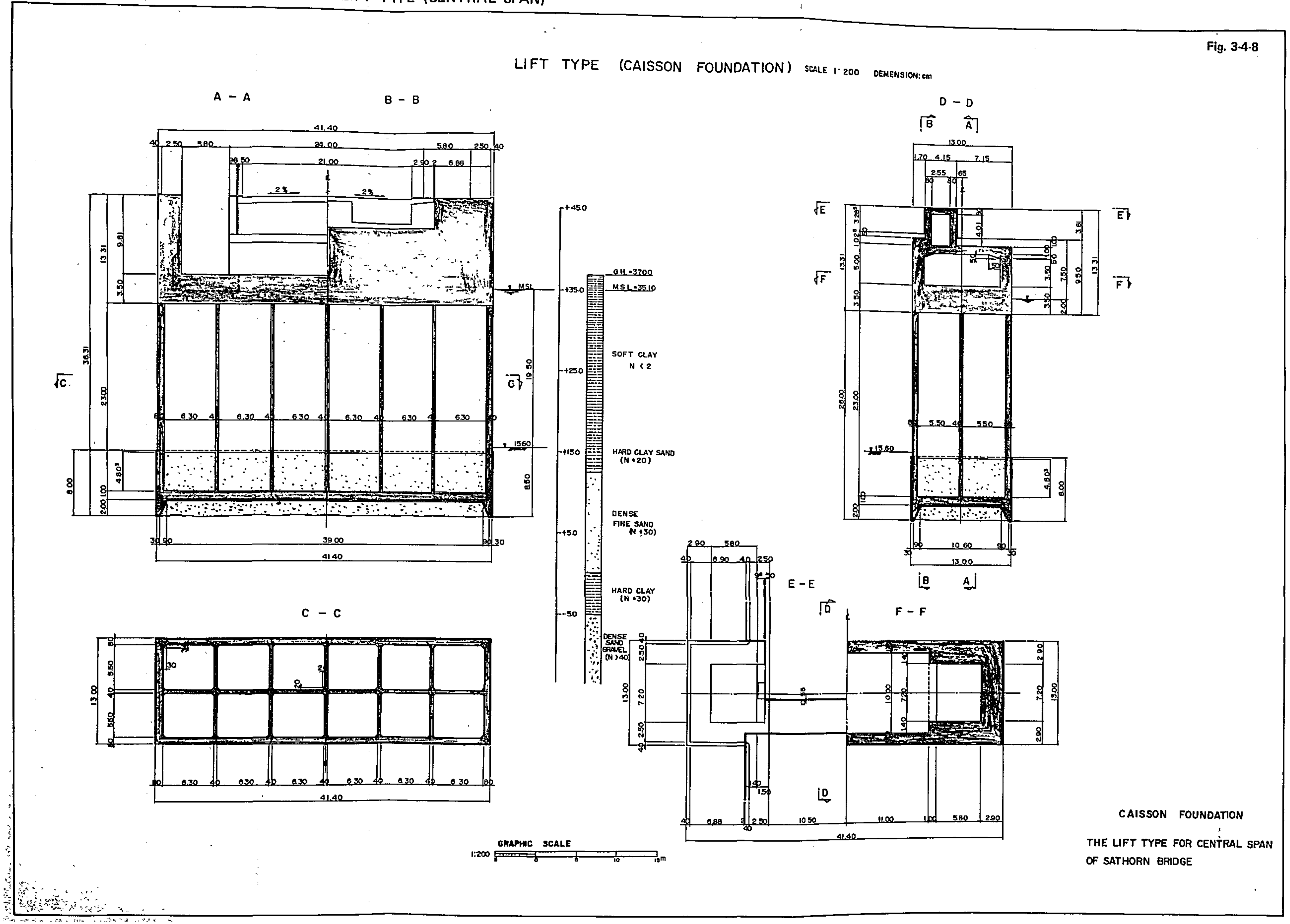


Fig. 3–4–9 PILE FOUNDATION FOR LIFT TYPE (CENTRAL SPAN)

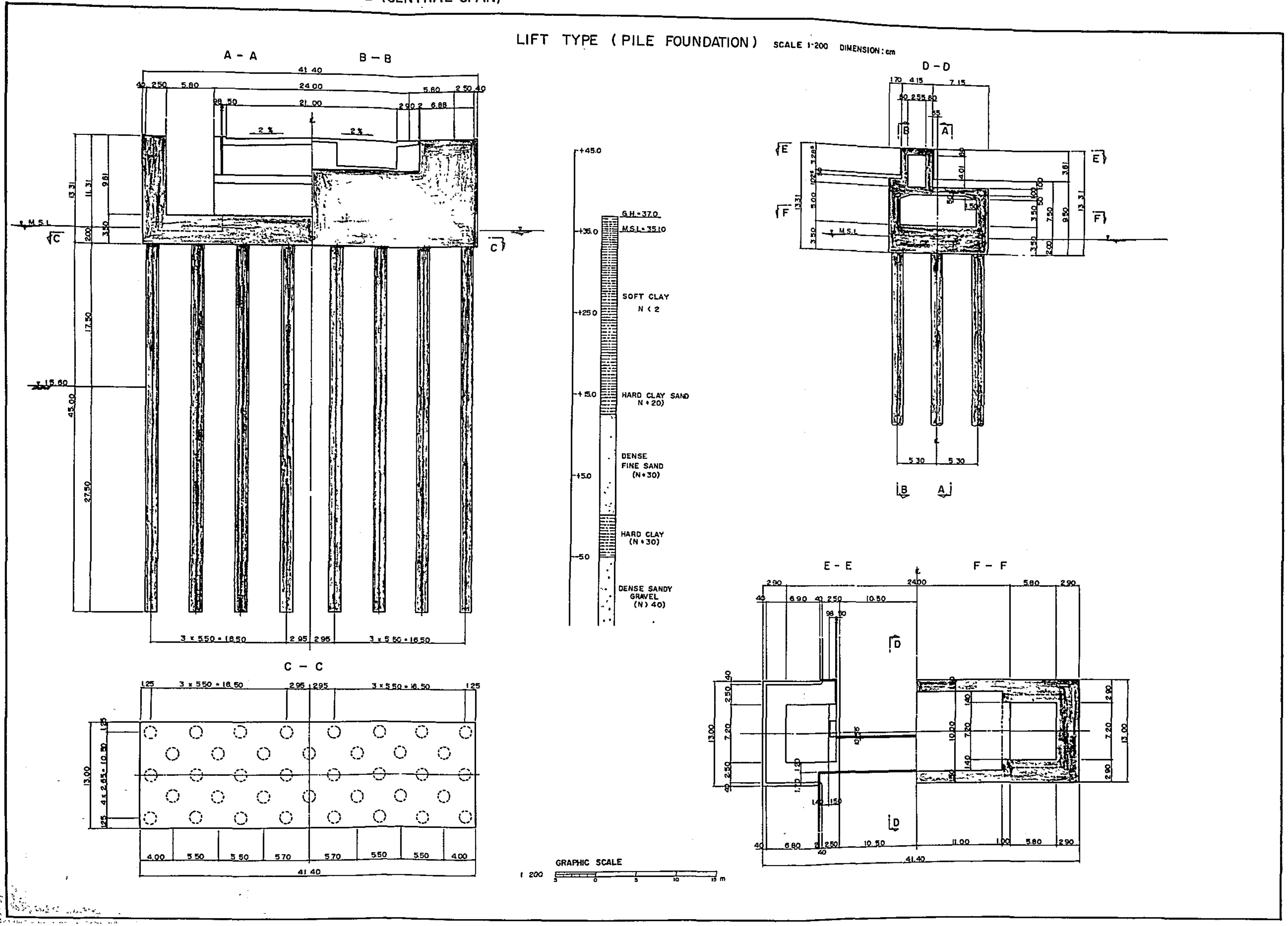


Table 3-4-3 Materials and Equipment for Superstructure of Central Span

Type / Materials & Equipment		Lift Type Q'ty.	Lift Type Remarks	Bascule Type Q'ty.	Bascule Type Remarks
Bridge		750 t	Main girders, expansion joints, handrails, shoes, drainage facilities.	1,350 t	Main girders, expansion joints, handrails, shoes, drainage facilities, anchor frame.
Grating		150 t	Inclusive of metal fittings, reinforcement.	170 t	Inclusive of metal fittings, reinforcement.
Mechanical Equipment		490 t	Wire rope and sheaves for counterweight, lifting devices, locking devices, and a set of accessories.	360 t	Trunnions, opening devices, locking devices, and a set of accessories.
Electrical Equipment		150 t	Inclusive of equipment for power supply, lighting equipment, signal equipment, and wiring materials.	150 t	Inclusive of equipment for power supply, lighting equipment, signal equipment, and wiring materials.
Tower		1,010 t	Tower, beams, anchor frame, curtain plates, control room.		
Total		2,550 t		2,030 t	
Concrete		420 m^3	Floor slab and pavement	450 m^3	Floor slab and pavement
Counterweight		240 m^3	Filling concrete (Specific gravity· 2.35)	610 m^3	Filling concrete (Specific gravity: 2.35)
		1,200 t	Steel Material (Specific gravity: 7.85)	3,500 t	Steel Material (Specific gravity: 7.85)
TOTAL	Concrete	660 m^3		1,060 m^3	
	Steel	1,200 t		3,500 t	

Table 3-4-4 Materials for Substructure of Central Span

Type \ Material	Concrete	Reinforcement	Steel Caisson
Bascule Type	6,550 m^3	980 ^{t}	182 ^{t}
Lift Type	8,100 m^3	890 ^{t}	186 ^{t}

Table 3-4-5 Comparison of Mechanism and Maintenance between Lift Type and Bascule Type

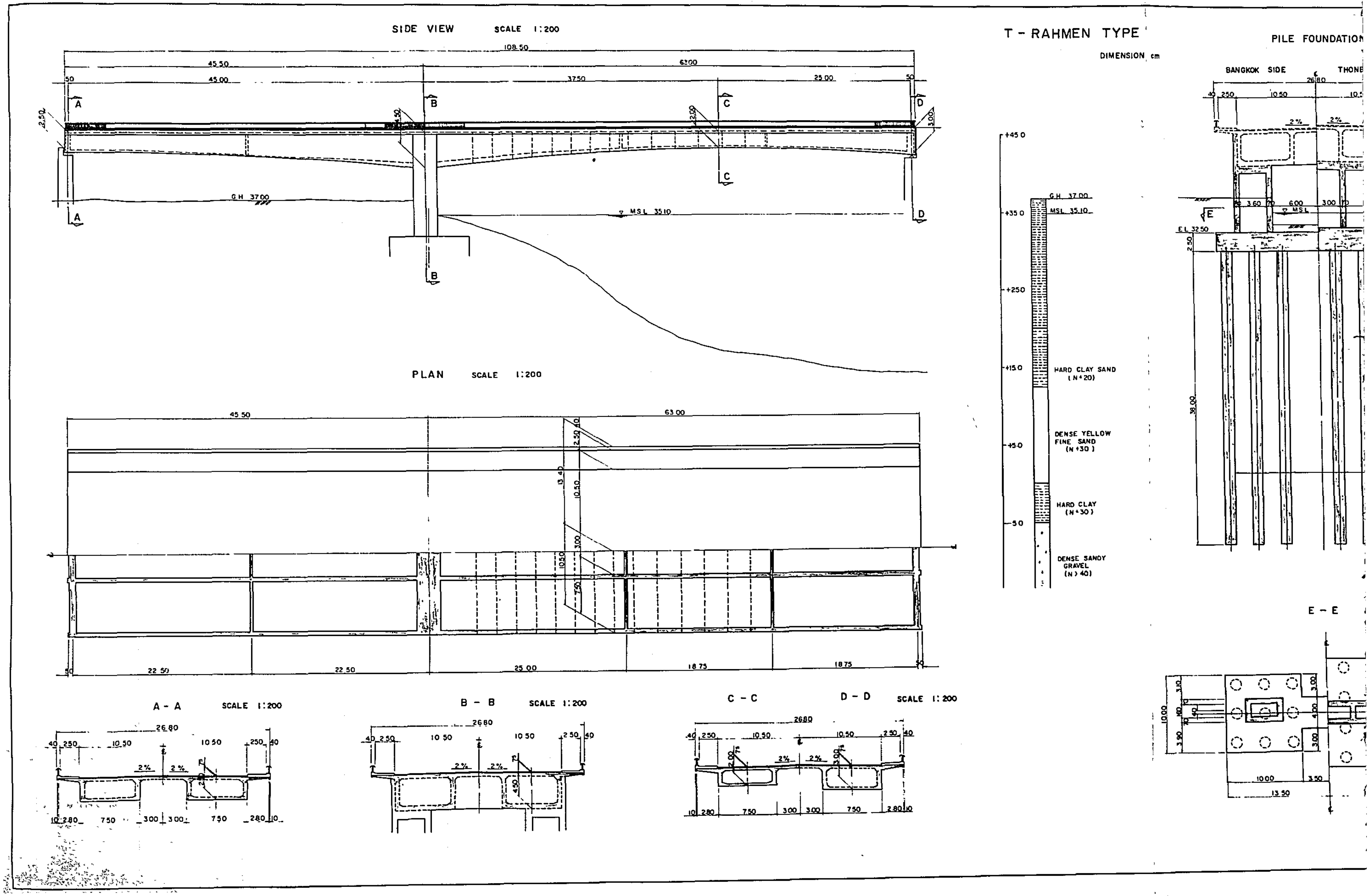
Item \ Type	Drum Winding Type Lift Bridge	Sector Gear Type Bascule Bridge
1. Mechanism	The mechanism, though rather complex, is well known and easy for engineers and operators to get used to.	Ditto
	Ward-Leonard speed control system necessitates the installation of DC motor and complex electric circuit.	Ditto (but no synchronizing device is needed)
	2 motors are required for 4 locking devices.	3 motors are needed for 6 locking devices.
	Elevator needed.	Elevator not needed.
2. Maintenance	The lifting mechanism mounted on a rigid frame is stable against ground settlement or pier displacement and assures easy maintenance of revolving or sliding parts. Initial cost is somewhat higher. Transformation into the fixed type can be readily achieved by removing the tower.	Mechanical parts (trunnions, adjustable shoes, locking devices, etc.) are more vulnerable to ground settlement and pier displacement than those of the lift type. The central portion cannot be remodelled into the fixed type bridge. Adjusting devices aginst the ground settlement and other adverse effects are provided.

Table 3-4-6 Cost Comparison for Side Span Construction

(Unit: ฿1,000)

Cost \ Type	T-rahmen		Continuous Girder	
	Caisson Foundation	Pile Foundation	Caisson Foundation	Pile Foundation
Superstructure	31,300	31,300	33,500	33,500
Substructure	16,900	16,100	16,900	15,300
Total	48,200	47,400	50,400	48,800

Fig. 3–4–10 T-RAHMEN FOR SIDE SPAN



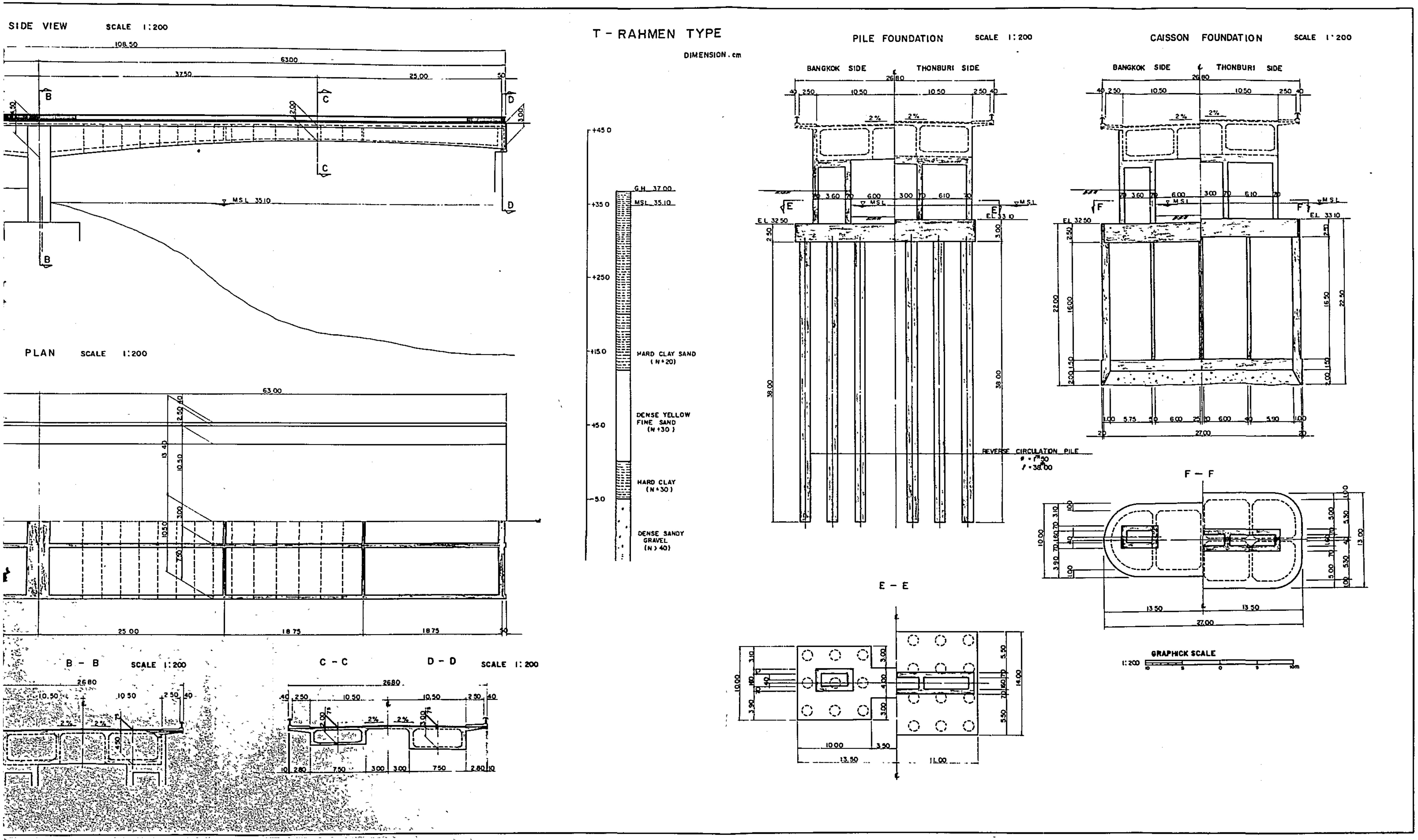
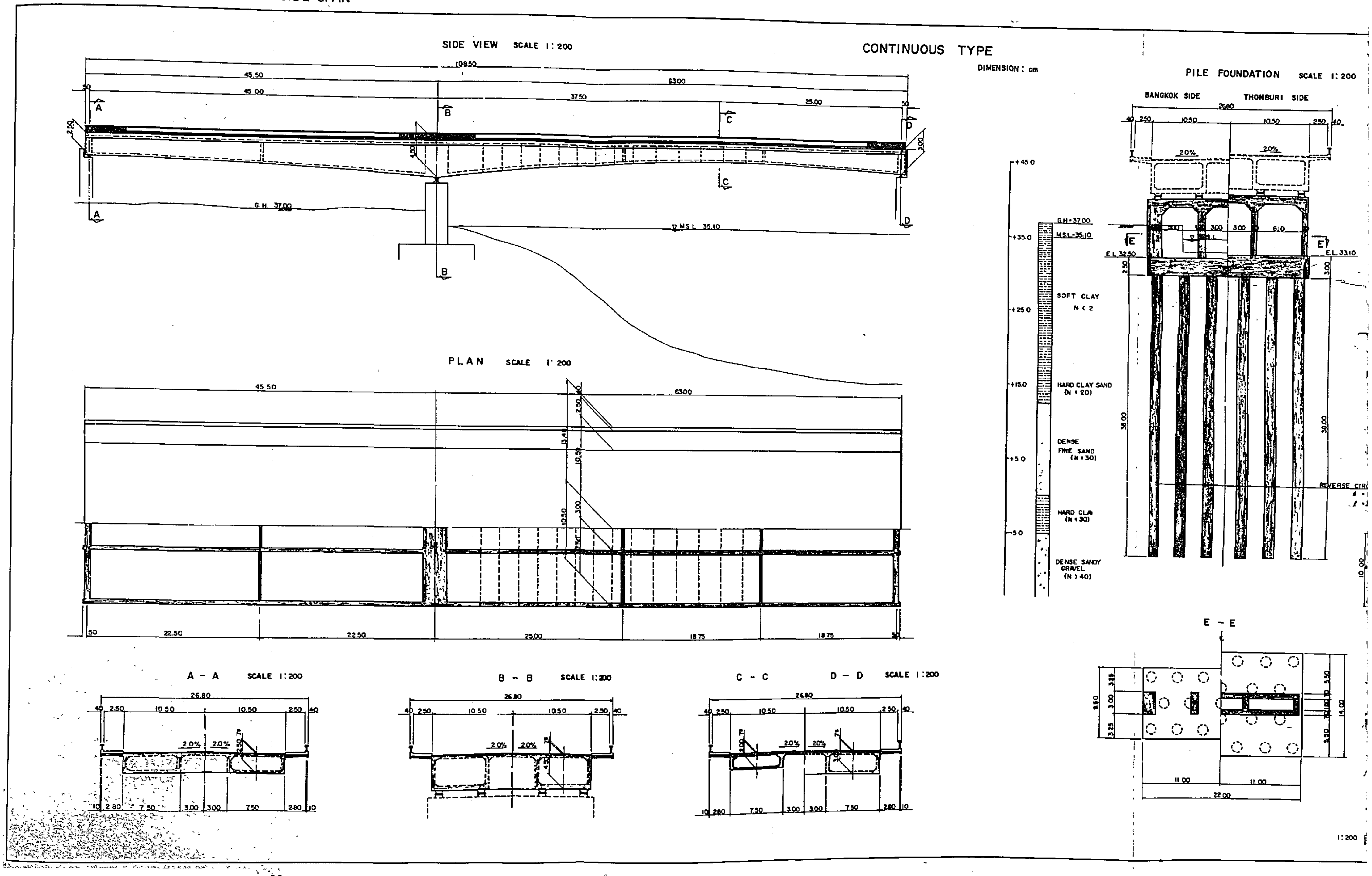
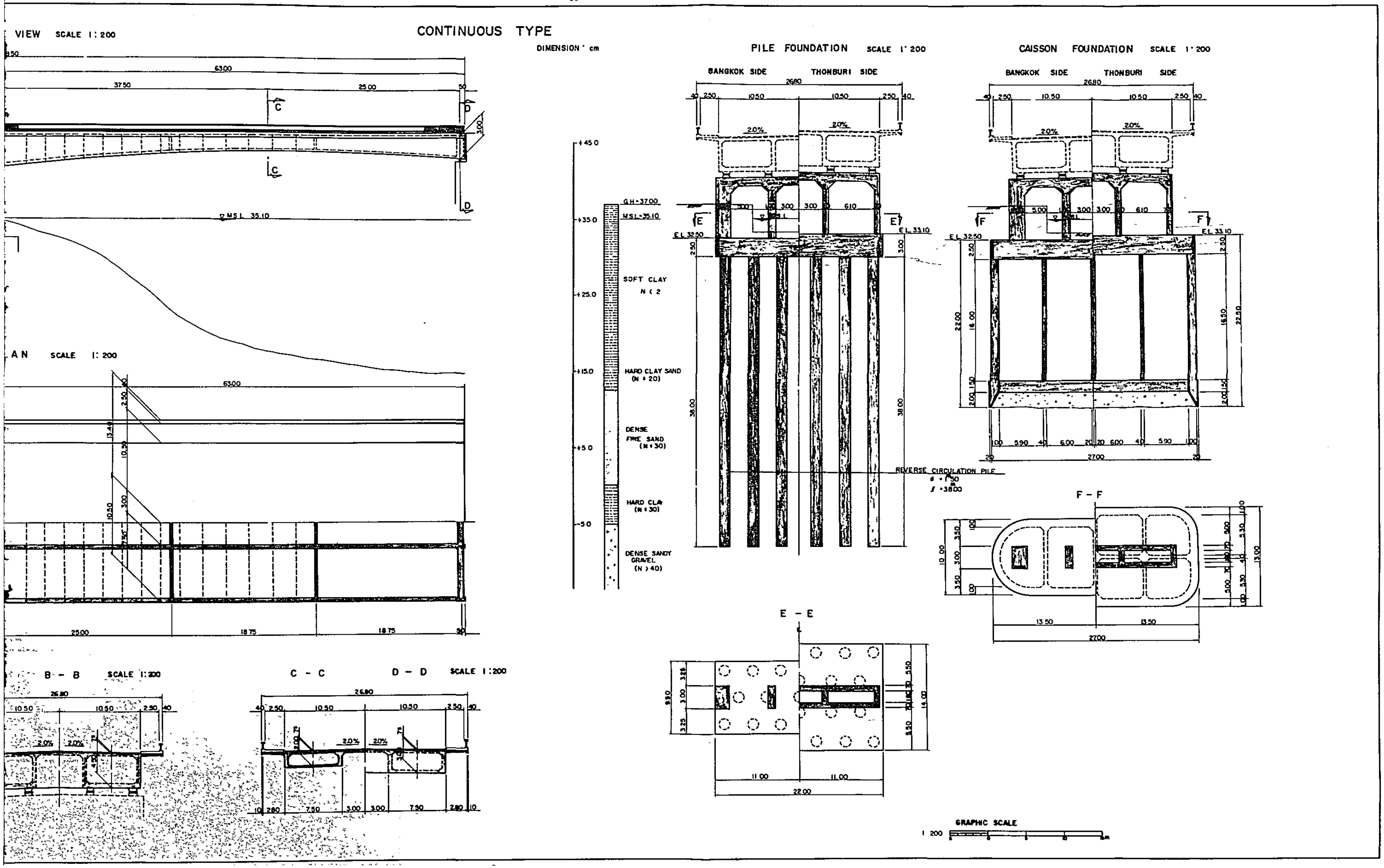

T - RAHMEN TYPE
DIMENSION . cm
SIDE VIEW SCALE 1:200
PLAN SCALE 1:200
PILE FOUNDATION SCALE 1:200
CAISSON FOUNDATION SCALE 1:200
BANGKOK SIDE
THONBURI SIDE
B - B SCALE 1:200
C - C
D - D SCALE 1:200
E - E
F - F
MSL 35.10
G.H. 37.00
HARD CLAY SAND (N=20)
DENSE YELLOW FINE SAND (N=30)
HARD CLAY (N=30)
DENSE SANDY GRAVEL (N>40)
REVERSE CIRCULATION PILE
EL 32.50
EL 33.10
GRAPHICK SCALE
1:200

Fig. 3-4-11 CONTINUOUS TYPE FOR SIDE SPAN




CONTINUOUS TYPE
DIMENSION : cm
VIEW SCALE 1:200
PLAN SCALE 1:200
▽M.S.L. 35.10
B - B SCALE 1:200
C - C
D - D SCALE 1:200
PILE FOUNDATION SCALE 1:200
CAISSON FOUNDATION SCALE 1:200
BANGKOK SIDE
THONBURI SIDE
G.H.=37.00
M.S.L.=35.10
SOFT CLAY
HARD CLAY SAND (N = 20)
DENSE FINE SAND (N = 30)
HARD CLAY (N = 30)
DENSE SANDY GRAVEL (N > 40)
EL 32.50
EL 33.10
REVERSE CIRCULATION PILE
E - E
F - F
GRAPHIC SCALE
1:200

The rough estimate of material requirements for these different types is shown in Tables 3-4-7 and 3-4-8. From these tables, it is clear that the T-rahmen is preferable to the continuous girder because it can dispense with the massive shoes (about 45 t) and saves about 10 tons of P.C. steel reinforcement.

The T-rahmen type is also advisable as far as construction and maintenance are concerned since it requires no bearing shoe on the piers which is indispensable for the continuous girder.

(4) Approaches

The structural outlines of the different types of approaches are illustrated in Figs. 3-4-12 through 3-4-14.

The construction cost of the approaches is shown in Table 3-4-9.

Furthermore, the rough estimate of materials needed for the approaches is given in Table 3-4-10.

There will be a small change in the length of the central span depending on which of the two types, the bascule or the lift, is adopted. Consequently there may be minor change in the length of the side span. However, it is negligible and does not produce any noticeable discrepancy in cost or volume of materials required. Figures given in Tables 3-4-9 and 3-4-10 are therefore obtained on condition that the bascule type will be adopted for the central span.

Table 3-4-7 Material Requirements for Side Span Substructure

Material / Type	Concrete	Reinforcement	Steel Casing
Caisson Foundation	7,100 m^3	890 ^{t}	–
Pile Foundation	1,640 m^3	210 ^{t}	650 ^{t}

Table 3-4-8 Material Requirements for Side Span Superstructure

Material / Type	Concrete	Reinforcement	Steel Casing
T-rahmen	6,400 m^3	580 ^{t}	240 ^{t}
Continuous Girder	6,400 m^3	580 ^{t}	250 ^{t}

Fig. 3–4–12 APPROACH (SPAN LENGTH L = 18.2 M)

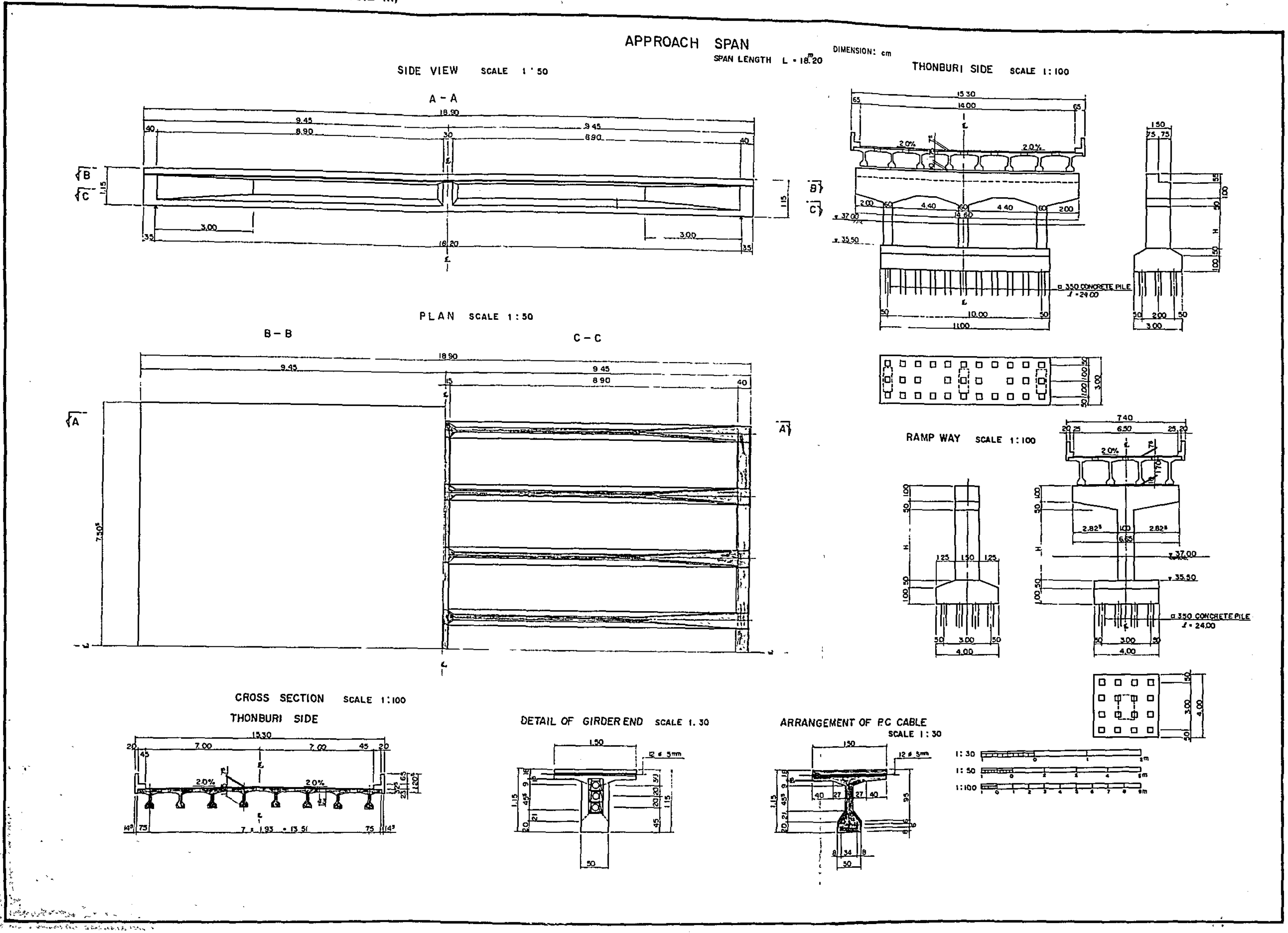


Fig. 3-4-13 APPROACH (SPAN LENGTH L = 26.0 M)

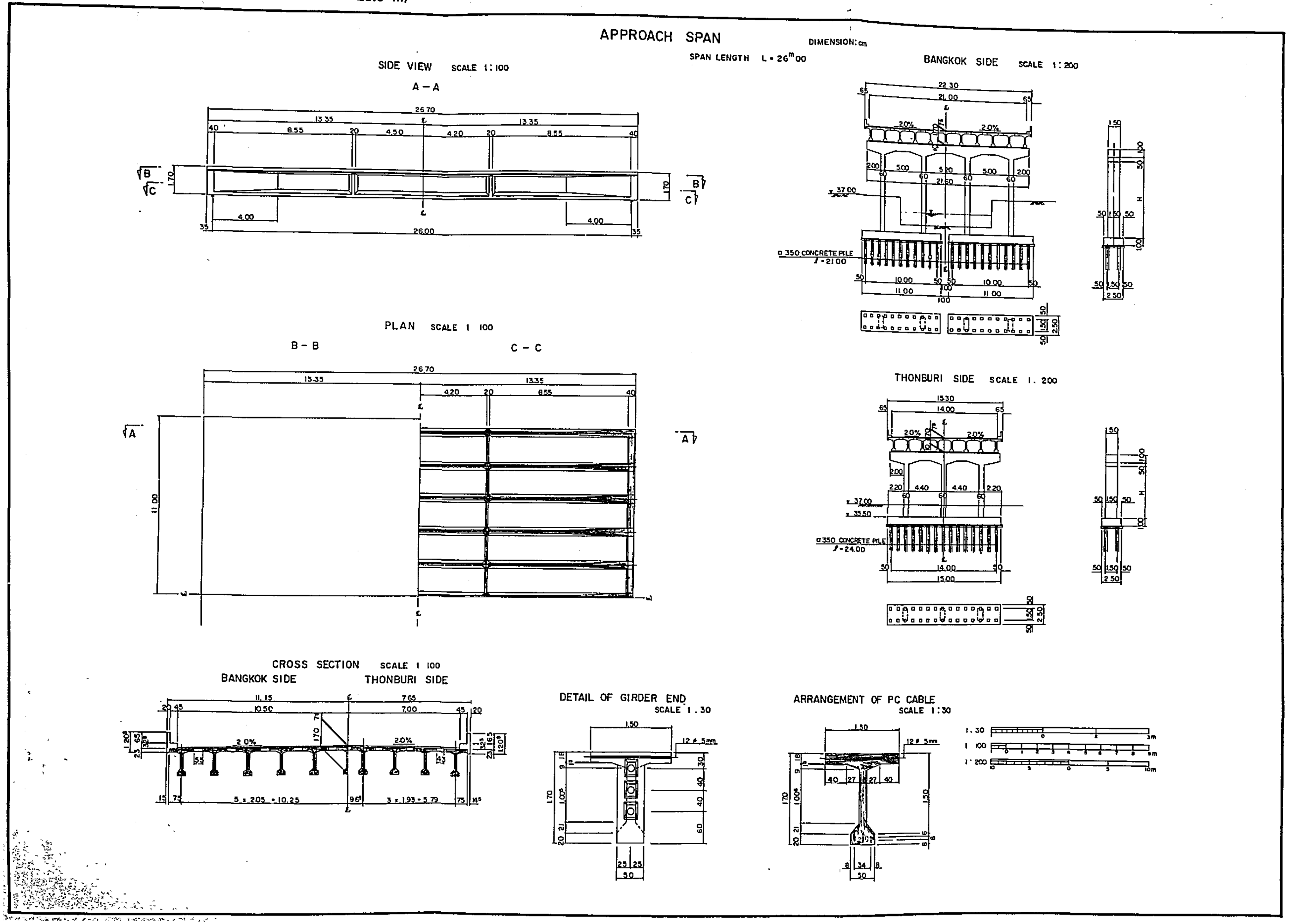


Fig. 3-4-14 APPROACH (SPAN LENGTH L = 35.0 M)

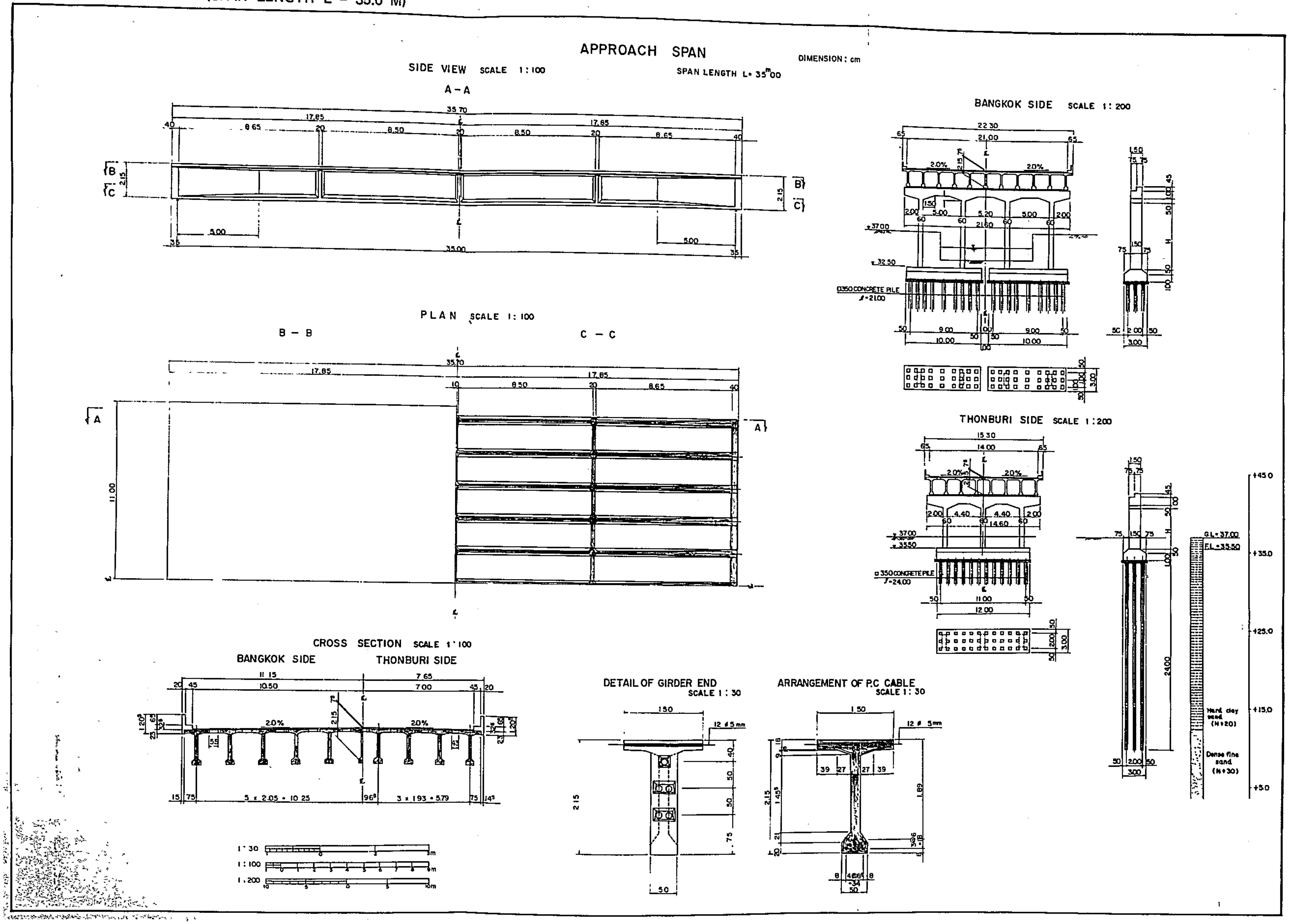


Table 3-4-9 Cost Estimation of Approaches

(Unit: ฿1,000)

Superstructure	32,400
Substructure	35,600
Total	68,000

Table 3-4-10 Quantities of Materials for Approaches

Material	Concrete	Reinforcement	P.C. steel material	P.C. pile □ 350
Superstructure	9,700 m^3	750 ^{t}	240 ^{t}	–
Substructure	7,400 m^3	1,090 ^{t}	–	1,929
Total	17,100 m^3	1,840 ^{t}	240 ^{t}	1,929

3-5 Findings and Problems in Preliminary Design

(1) Structural Type

As is already clear from the comparative study made in the preceding section, the bascule type is economically most advisable for the central span because it calls for the least amount of foreign currency for importation and demands very little mechanical and electrical maintenance cost. It might be added that the bascule type excels in appearance and therefore this type is recommended for the central span. As for its operating mechanism, employment of the sector gear is most recommendable.

With respect to the side spans, it is advised that the T-rahmen with a caisson foundation be adopted for economical as well as technical reasons. The recommended type incurs the lowest cost and yet entails little difficulty in both construction and maintenance.

For the superstructure of the approaches, the P.C. T-beam is recommendable, and the use of square P.C. piles (35 cm x 35 cm) is considered advisable for the foundation.

(2) Material Requirements and Construction Cost

The materials and work required for the recommended structure, for which a brief explanation has already been given in 3-4, are tabulated in detail in Table 3-5-1 (1).

Table 3-5-1 (2) shows that of the superstructure of the central span. The first sub-total in this table shows the weight of the materials to be fabricated in the workshop, while the second sub-total shows the same including the weight of the concrete and other things to be used at the site.

Table 3-5-1(1) Total Quantities of Materials and Equipments

	Concrete (m³)				Steel materials	Reinforcement	Steel materials for counterweight	Reinforcement (φ7)	Mechanical & electrical equipment	Forms	P. C. piles □350	Steel shoes	Steel sheet piles
	δ28=350 Kg/cm²	δ28=240 Kg/cm²	Under-water work, filling & levelling	Total	(t)	(t)	(t)	(t)	(t)	(m²)	(pcs)	(t)	(t)
Main Bridge	5,440	20,440	3,990	29,870	1,520	3,430	3,500	240	510	52,300	–	380	200
Superstructure	5,440	890	610	6,940	1,520	520	3,500	240	510	18,500	–	–	–
Central Span	–	450	610	–	1,520	–	3,500	–	510	–	–	–	–
Side Span	5,440	440	–	–	–	520	–	240	–	18,500	–	–	–
Substructure	–	19,550	3,380	22,930	–	2,910	–	–	–	33,800	–	380	200
Central Span	–	13,100	2,220	–	–	1,960	–	–	–	26,000	–	360	–
Side Span	–	6,450	1,160	–	–	950	–	–	–	7,800	–	20	200
Approaches	5,740	11,030	340	17,110	–	1,850	–	240	–	–	1,930	–	–
Superstructure	5,740	5,590	–	–	–	910	–	240	–	–	–	–	–
Substructure	–	3,890	200	–	–	780	–	–	–	–	1,470	–	–
Retaining wall, etc.	–	1,550	140	–	–	160	–	–	–	–	460	–	–
Total				m³ 46,980	t 1,520	t 5,280	t 3,500	t 480	t 510		1,930	t 380	t 200

Table 3-5-1(2) Materials and Equipments for Superstructure of Central Span

Item	Quantity	Remarks
Bridge	1,350 t	Steel beam, expansion joint, handrail, shoe, drainage facilities and anchor frame.
Grating	170 t	Metal fittings, reinforcement for curve stone.
Mechanical Equipments	360 t	Trunnion, switch gear, lock device, and a set of accessories.
Electrical Equipments	150 t	Facilities for power supply, lighting equipment and signal equipment, wiring materials.
Sub-total	2,030 t	
Concrete	450 m³	Floor slab and pavement
Counterweight	610 m³	Concrete mortar
	3,500 t	Steel materials
Sub-total	1,060 m³ 3,500 t	

Table 3-5-2 Construction Cost of the Superstructure of the Central Span

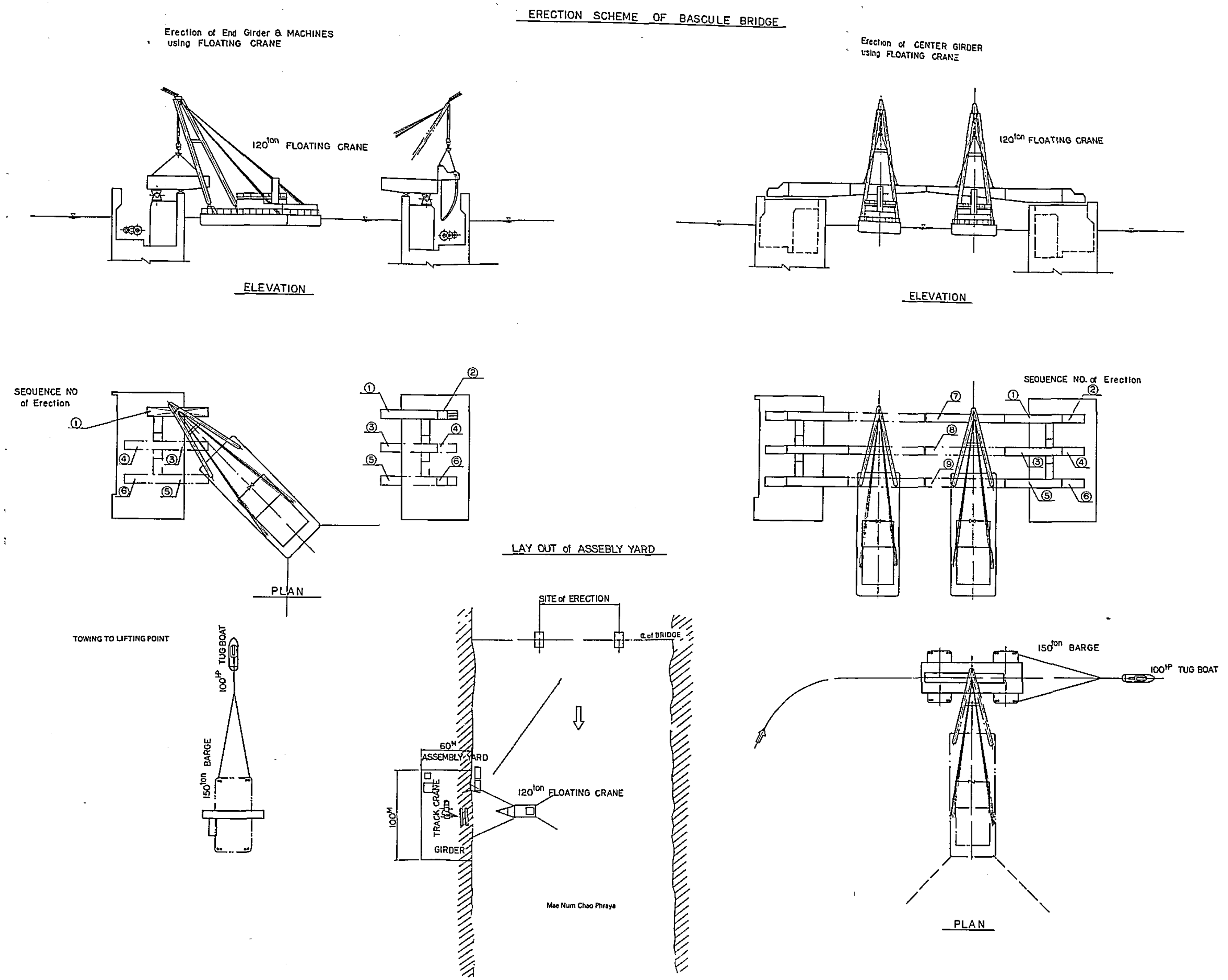
(Unit: B1,000)

Item	Foreign Currency	Local Currency	Total
Fabrication	74,900	–	74,900
Transportation	12,000	4,700	16,700
Erection	10,600	11,700	22,300
Sub-total	97,500	16,400	113,900
Overhead cost	11,700	2,000	13,700
Total	109,200	18,400	127,600

Table 3-5-3 Construction Cost Excluding Superstructure of Central Span

Item		Foreign currency	Local currency	Total
Substructure	Central Span	14,374	22,104	36,478
	Side Span	3,668	7,907	11,575
	Approach	1,840	23,334	25,174
Superstructure	Side Span	8,778	12,701	21,479
	Approach	5,714	15,248	20,962
Slab and pavement	Whole Bridge	2,153	3,608	5,761
Auxiliary Works	Whole Bridge	329	1,056	1,385
Preparatory Works	Whole Bridge	350	2,520	2,870
Rent for equipment	Whole Bridge	1,459	1,264	2,723
Engineering	Whole Bridge	12,257	11,839	24,096
Overhead cost	Whole Bridge	5,658	11,287	16,945
Total		56,580	112,868	169,448

Fig. 3–5–1 ELECTION SCHEME OF BASCULE BRIDGE



The construction cost of the superstructure of the central span is shown in Table 3-5-2, and that of other portions in Table 3-5-3. Totalling these values, the construction cost of the proposed Sathorn Bridge amounts to 297 million Bahts in total.

(3) Construction Method and Schedule

(a) Superstructure of the Central Span

The erection of superstructure of the central span is to be carried out in the following sequence.

The positions of each piece of equipment on the bridge pier must be located by the combined application of triangulation and the distance survey. Then, the electrical equipment is to be carried on the pier before bridge erection. This is to be followed by the installation of the trunnion bearing at the specified position, and then by the girder erection.

The main girders divided into three blocks, i.e., the supporting block, the counter-weight block and the cantilever block are to be erected by means of a 120 t floating crane. (See Fig. 3-5-1).

(b) Central Span Substructure, Side Span and Approach

The substructure of the cental span is to be constructed by the floating caisson method as outlined in Fig. 3-5-2.

The steel caisson is to be built and towed to the designated position in the river and filled with concrete. The upper portion of the caisson is built up gradually with concrete so as to make it sink little by little until it settles on the river bed. When the caisson settles to the bottom, further excavation down to the specified position is to be carried out by the ordinary pneumatic caisson method.

Fig. 3–5–2 (1) FLOATING CAISSON METHOD (TOWING THE STEEL CAISSON ONTO WATER)

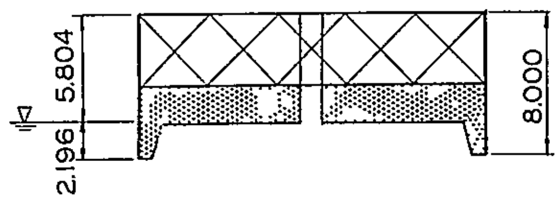


Fig. 3–5–2 (2) FLOATING CAISSON METHOD (CONCRETE PLACING IN THE STEEL CAISSON)

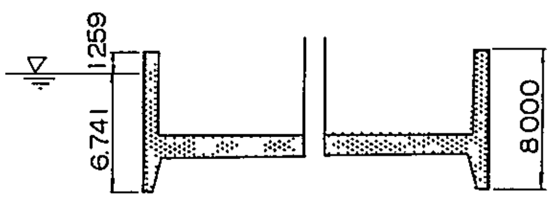


Fig. 3–5–2 (3) FLOATING CAISSON METHOD
(SINKING THE CAISSON WHILE CONCRETING)

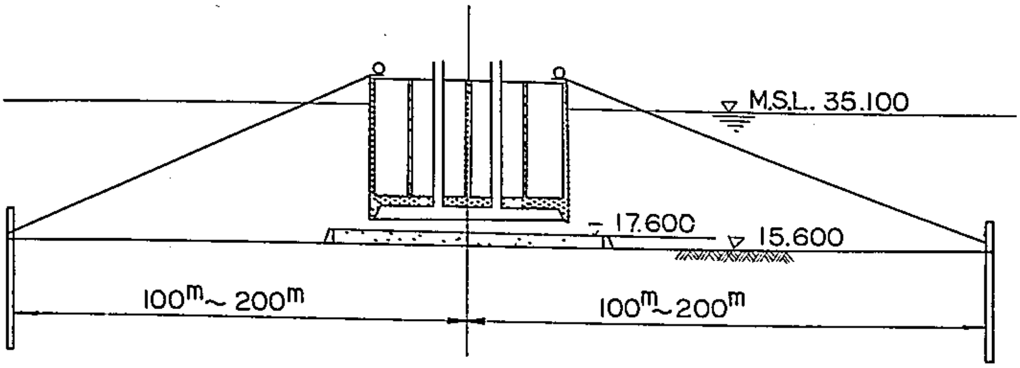
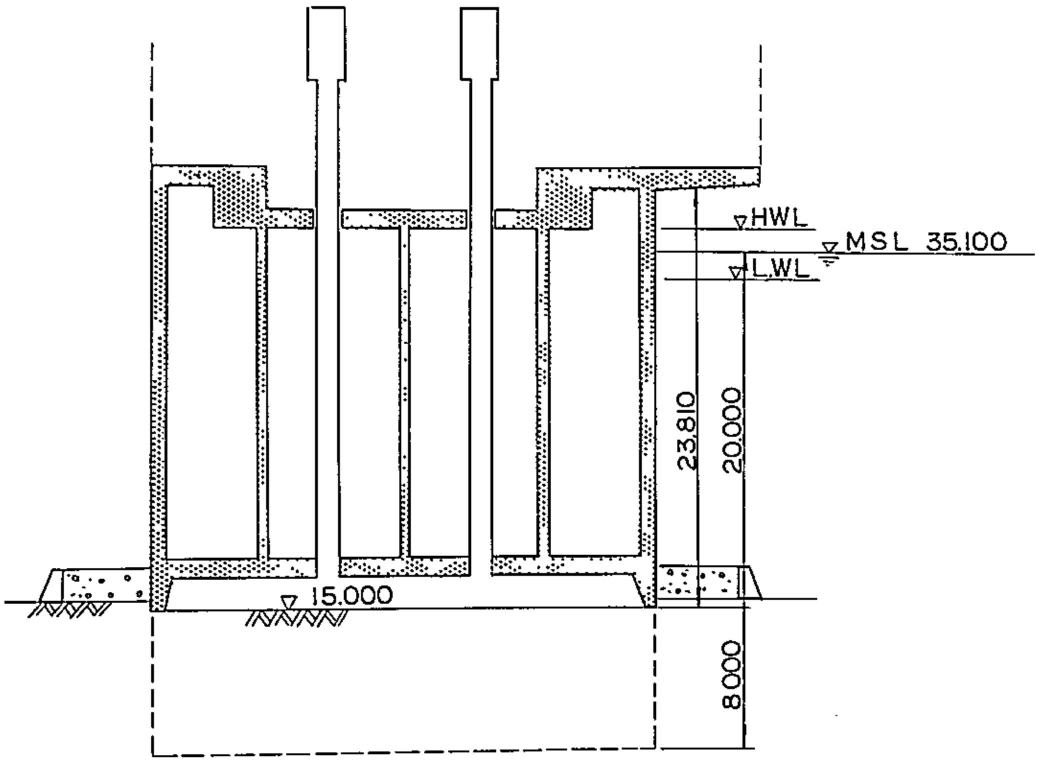


Fig. 3–5–2 (4) FLOATING CAISSON METHOD
(EXCAVATION AND SINKING USING THE PNEUMATIC METHOD)



The superstructure of the side spans on land should be constructed by the cast-in-place method using scaffolding on both the Thon Buri and Bangkok sides. As shown in Fig. 3-5-3, the side span on land is to be erected by the all staging method. For the side span over the river, the cantilever method with movable scaffolding is to be employed for the 35 m section adjacent to the central pier, while the cast-in-place method with the erection girder should be adopted for the construction of the main girder in the rest of the span. (See Fig. 3-5-3). Since the land on which the side span is to be built is so soft, it is necessary to drive piles of about 25 m in length. Upon completion of the over-land portion by the all staging method, the movable scaffolding is to be assembled for the cantilever construction of the river portion.

The caisson foundation for the central pier of the side span is to be started with the construction of an artificial island made of sheet pile cofferdam. The sinking operation is to be carried out using the open excavation method.

The foundation work is thus complete when the caisson of the specified depth has been sunk to the planned position.

The superstructure of the approaches should consist of precast beams erected by the post-tensioning method. The main girders, having five different lengths ranging from 18.9 m to 35.7 m, should all be fabricated at the assembly yard near the construction site and erected by means of a portal crane shown in Fig. 3-5-4.

(c) Construction Schedule

As is clear from the Construction Schedule (Table 3-5-4) about 30 months will be required for the construction of the Sathorn Bridge. The schedule has been prepared with special concern for the navigation on the Chao Phraya and the efficient utilization of erection equipment.

(4) Problems to be reconsidered

The preliminary designs presented in the foregoing pages seem to leave room for further studies and discussions.

The first problem in the proposed design is the fact that it was prepared prior to the completion of the boring survey. It is presumed in this report that almost the same geological conditions prevail throughout the Bangkok area. However, if a large discrepancy is discovered, the conclusions reached in this report would have to be largely altered.

The second question is the effect of the proposed bridge construction on the flow of the Chao Phraya. The Sathorn Bridge is to be built near Bangkok at a point where the river has a narrower width. The piers to be built in the river will reduce the river width by about 30%, and this could seriously effect the current and flow pattern of the river, and could even accelerate the scouring on the river bed. Surveys and studies to answer this question are absolutely necessary.

The third and the last problem is how the high construction cost can be reduced to the minimum. The cost estimations given in this report are all based on the preliminary designs, but they produced an unexpectedly high cost. By restudying the contents of this report, it

Fig. 3–5–3 GIRDER ELECTION FOR SIDE SPAN

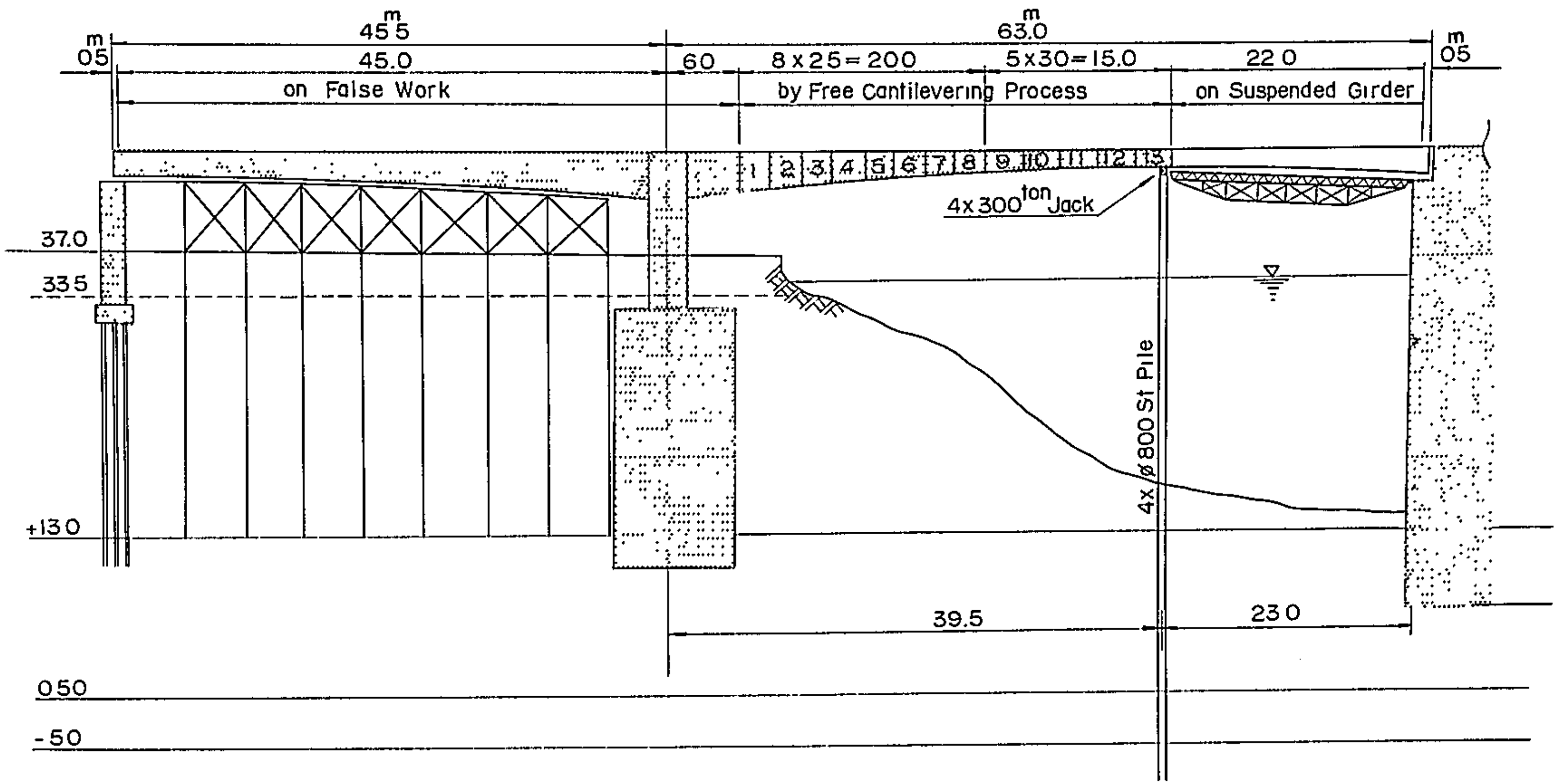


Fig. 3–5–4 GIRDER ELECTION FOR APPROACH SPAN

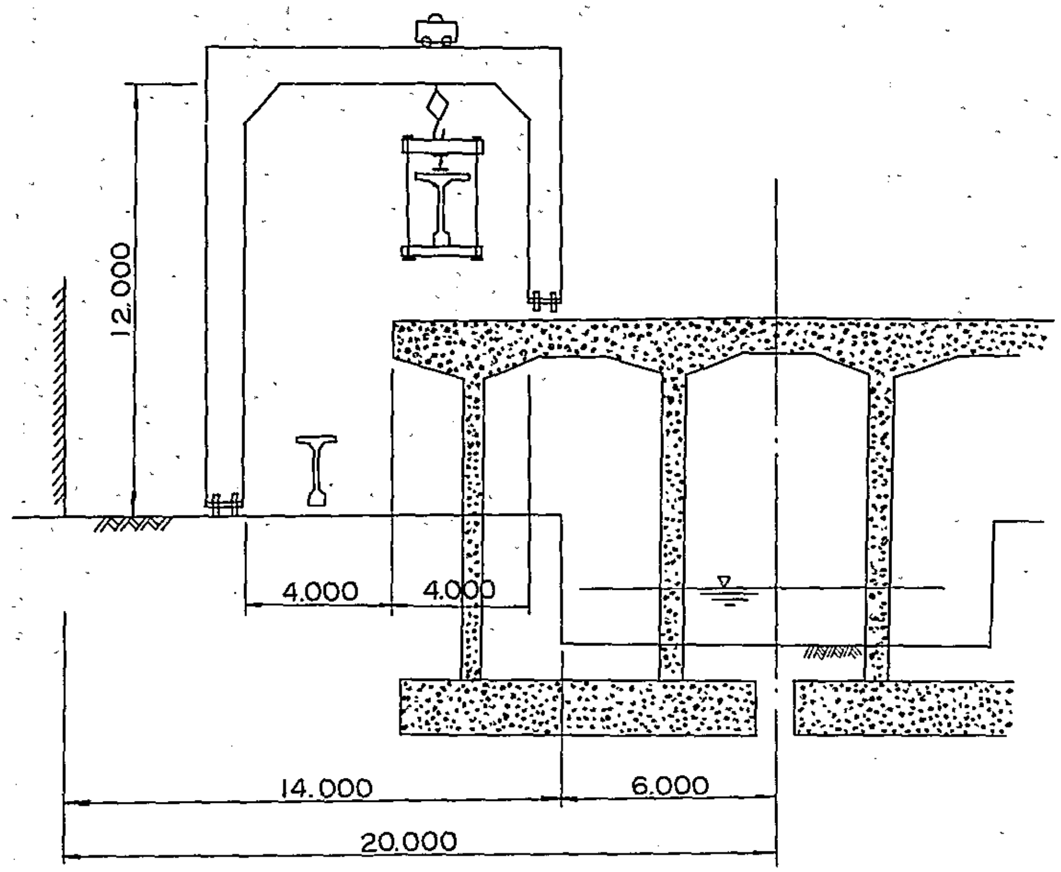
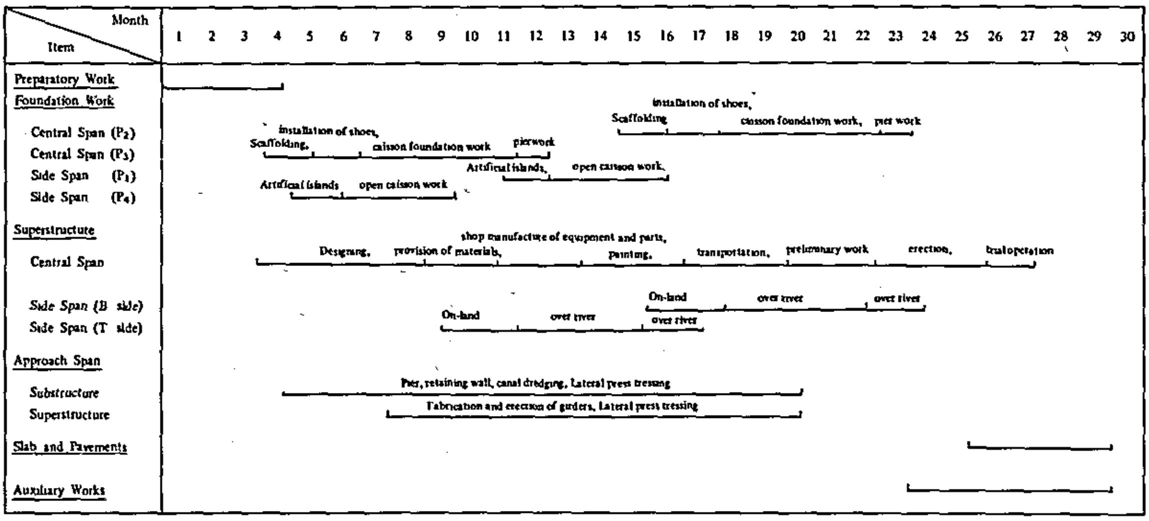


Table 3-5-4 Erection Schedule of the Sathorn Bridge



was found that it could be cut down. For this purpose, however, the conditions for constructing the bridge would have to be reviewed once again in the detailed designing stage. Using the contents of this report as the basis, the construction conditions should be reviewed again.

A recommendable plan for cutting down the cost is to alter the floor slab of the bascule bridge from the solid type grating to the open type grating. This will reduce the cost of the superstructure by about 8% and also makes it possible to use a smaller caisson than is required in the present plan. This alteration in the floor system, if adopted, will also result in a cost reduction in the substructure by about 10%. It may be added that the use of a smaller caisson is desirable also in view of the current and flow pattern of the river.

This report has been prepared on the assumption that the best materials available would be used in order to make future maintenance and operation easier. By using materials of ordinary quality or by omitting some facilities including the industrial TV, about 10% of the cost for the superstructure of the bascule bridge can also be saved.

The adoption of a steel bridge for the side spans deserves consideration if the cost is to be cut down further.

As described above, there still remain a number of problems that await solutions in the stage of the detailed design. However, finding the solutions to all these problems is beyond the scope of this report.

Nevertheless, the Japanese Survey Team believes that this report wil provide the most important and useful data needed for the detailed design.