REPUBLIC OF SINGAPORE

PUBLIC WORKS DEPARTMENT
MINISTRY OF NATIONAL DEVELOPMENT

THE FEASIBILITY STUDY OF SELECTED EXPRESSWAYS

FINAL REPORT
(EXECUTIVE SUMMARY)

MARCH 1991

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JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of Republic of Singapore, the Japanese Government decided to conduct a feasibility study of Selected Expressways in Singapore and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Singapore a survey team headed by Mr.Kazuro Yanagida, composed of members from Oriental Consultants Co.,Ltd.,from May to December 1990.

The team held discussions with the officials concerned of the Government of Singapore, and conducted field surveys. After the team returned to Japan,further studies were made and the present report was prepared.

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

I wish to express my sincere appreciation to the officials concerned of the Government of Singapore for their close cooperation extended to the team.

March 1991

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

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CONCLUSION AND RECOMMENDATIONS

1. CONCLUSION

(1) Overview

The Study concluded, after lengthy and in-depth investigations and analyses in Singapore during which time valuable advices were received from the concerned officials of PWD (Public Works Department), that the improvement of PIE (Pan Island Expressway) and constructions of proposed KLE (Kallang Expressway) and PYE (Paya Lebar Expressway) were necessary in due course, that the alternatives selected for each expressway were feasible in every aspects of technical, socio-economy and economics, and that the implementation of such projects would contribute to national development.

(2) PIE

An alternative for at-grade increase of lanes, as a rule, was selected for the improvement of PIE between the PIE/BKE (Bukit Timah Expressway) Interchange and the Aljunied Flyover excluding the interchanges at the PIE/CTE and PIE/Woodsville, which were outside the scope of the Study.

Various alternatives were studied; such as underground, bypass and grade separated routes. The final alternative was found to be more superior in technical and economical aspects over the others.

All the existing structures, except the PIE/Toa Payoh Interchange, were proposed to be retained. New structures were planned to be added at interchanges and main expressway bridges. The flyover at PIE/Toa Payoh Interchange, which had insufficient head room clearance for the main expressway, was proposed to be completely refurbished to manage the existing problems and to cope with proposed improvements.

For the section between the interchanges of PIE/Thomson and PIE/CTE where an early tendering for the improvement works was planned, advices were sought by the PWD officials on the Study Team's proposals finalizing them to be in time for the tendering.

Maps of one in 1,000 and smaller were used. The final alternative was presented on drawings of one in 1,000 at all the interchanges, the stretch of PIE between the interchanges of PIE/CTE and PIE/Thomson; and one in 2,000 at other locations.

(3) KLE

An alternative of viaduct/tunnel structure was selected. The route was proposed to cross over the ECP (East Coast Parkway) and Geylang River by viaduct/bridge; to the Kallang Park by a tunnel of 495m long; to stay semi-depressed under Mountbatten Road, Geylang Road, Sims Avenue and MRT; and to finally climb up to cross over the PIE and to link up with the PYE.

Interchanges were studied at the ECP/KLE for full accesses, at the KLE/Mountbatten/Geylang for the underground major accesses with traffic directions from the city and at the PIE/KLE/PYE for full accesses.

Viaducts were planned to use standardized girders for both economics and aesthetics considerations. The bridge over Geylang River was proposed to be a three span continuous PC (Prestressed Concrete) box girder.

The tunnel would require a longitudinal forced ventilation by

jet fans. The length of the tunnel was proposed to be shortened as much as possible to reduce concentration of contaminated air and the semi-depressed section was utilized more.

A viaduct alternative for the whole length of the KLE remained competitive until the very end of evaluation as it possessed some advantages over the final selected one particularly on traffic safety. The recommendation was based largely on the aesthetic implications of the viaduct structures which, in the local context, might be viewed as unacceptable. The tunnel alternative was planned to pass through the portal with a tight 600m curve on 3% gradient, conditions which were known to be undesirable from the viewpoint of traffic accidents. This point should be looked into again prior to implementation.

The Study was conducted using one in 2,000 maps and smaller. Drawings of one in 2,000 scale were prepared for the final alternative.

(4) PYE

An alternative to make use the green belt of Air Base was selected. The proposed expressway should start from the PIE as an extension of the KLE, pass over the Pelton Canal by a viaduct, stay on the viaduct until the green belt where it should be at-grade. Flyovers were proposed at the crossings of Tampines Road and new Punggol Road.

Interchanges were proposed at Paya Lebar Road for full accesses, Hougang Avenue 3 for only a directional service from the Hougang area, at Tampines Road for full accesses, and at new Punggol Road for full accesses. The PYE/TPE (Tampines Expressway) should be connected as a junction for full directional services.

Viaduct should be standardized though, those over the Pelton Canal were proposed to be supported by three piers to preserve the capacity of the canal as much as possible.

Against the final alternative, there were others studied for different routes at such locations as the Air Base, Defu Avenue and Hougang Avenue and for other ideas of combining structures including a tunnel under the Air Base. The final alternative proved to be the most superior in overall aspect.

The drawings were prepared in a same scale as the KLE.

2. RECOMMENDATION

(1) Rezoning of Land Use at the Crossings of KLE, PYE and PIE

Proposed interchange had services to almost all the directions of three expressways. The roads and structures would be so complicated that some negative impact on the environ would be unavoidable. A change in land use from housings to others was recommended to reduce impact, at least to residents.

(2) Classified Use of Expressways

It was a common understanding to separate grade and role of expressways so that they could contribute more in terms of reduction in travel time and accidents. To keep a higher grade of an expressway, there would need several basics such as avoiding common bus stops and mixed usage with frontage roads, providing enough distance between interchanges, etc. Some of the expressway systems were recommended to be reviewed thoroughly in the light of such understanding prior to implementation.

1. INTRODUCTION

1.1 Project Background

The Public Works Department (PWD) had planned an expressway network in total of about 150 km and already about 100km had been completed. The remainder of the network was due for completion prior to the end of this decade.

The Kallang Expressway (KLE) was proposed to link the Pan Island Expressway (PIE) with the East Coast Parkway (ECP) and to form the eastern leg of the Central Area Expressway System (CAES). (see Fig.1) The Paya Lebar Expressway (PYE) was proposed to be the northward extension of the KLE. This expressway would serve four new towns to be constructed in the early part of the 21st century.

The PIE was found to be the most heavily used expressway in Singapore. The dual 3-lane expressway carried more than 120,000 vehicles per day and some stretch of the expressway was already operating at or close to its practical capacity during the peak periods. A means to increase the capacity was sought.

The Feasibility Study of Selected Expressways (Study) investigated the viability of the projects for KLE, PYE and PIE.

1.2 Study Objectives

The study objective was to conduct the feasibility study of the KLE and PYE, and improvement of the PIE between the Bukit Timah Expressway (BKE) and Aljunied Flyover.

1.3 Study Area

The study area covered the whole length of KLE and PYE and the sections of PIE between the BKE and Aljunied Flyover, excluding the interchanges at PIE/CTE (Central Expressway) and PIE/Woodsville, and their vicinities.

1.4 Study Procedure

The Study was conducted in two phases. The Phase-I Study comprised understanding present situation, projecting future traffic demand, formulating alternatives for schematic designs and selecting some for feasibility studies in the next phase. In the Phase-II Study, a feasibility study was carried out and final alternatives were selected for each target expressway.

1.5 Study Organization

From both Japanese and Singapore sides, organizations as shown in Fig.2 were set up for the conduct of the Study.

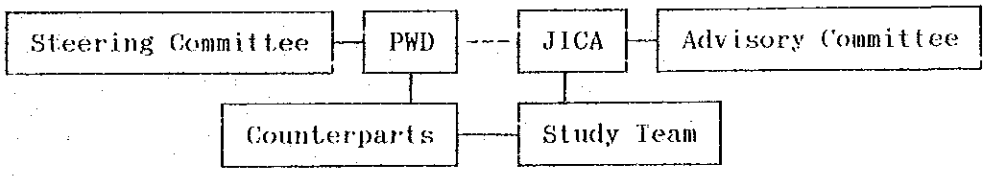


Fig.2 Study Organization Chart

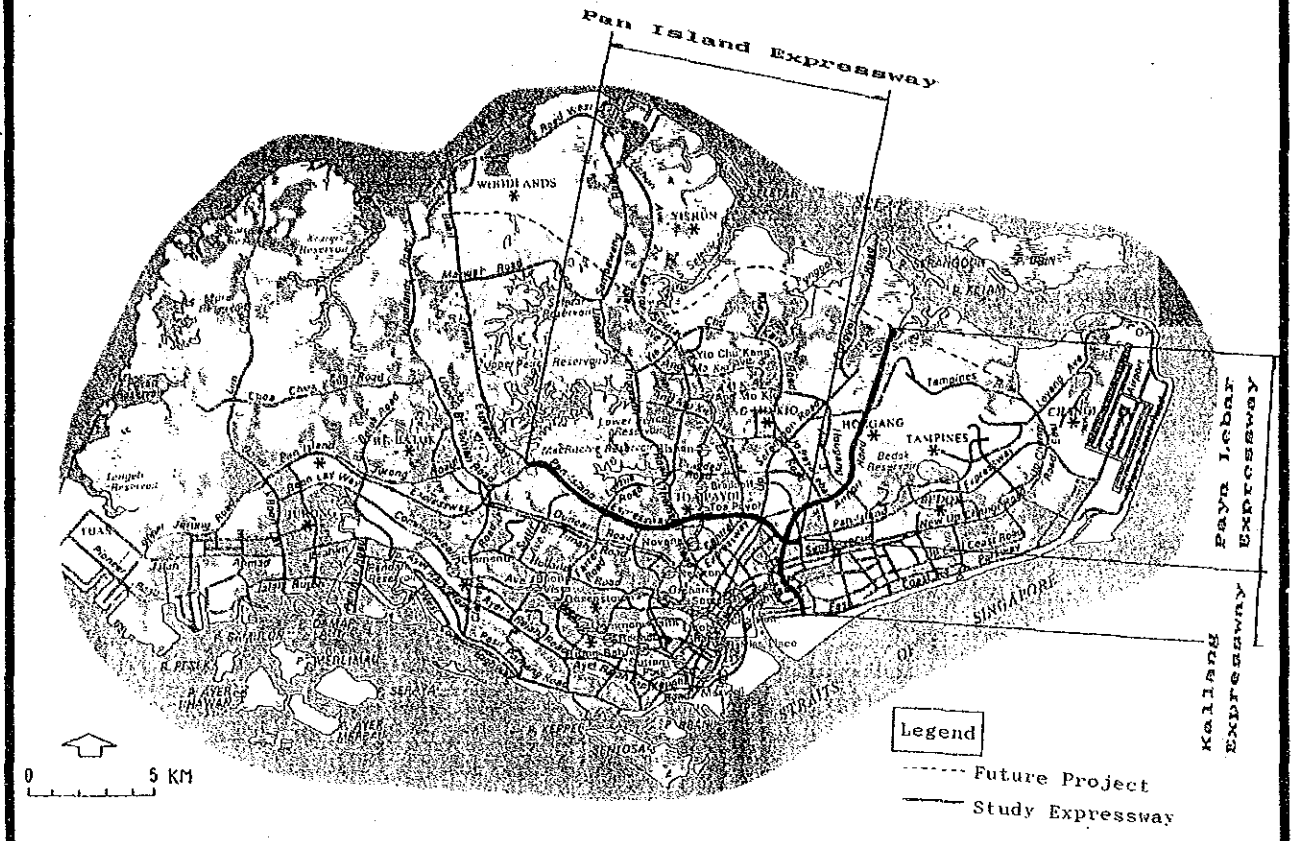


Fig. 1 Study Expressways

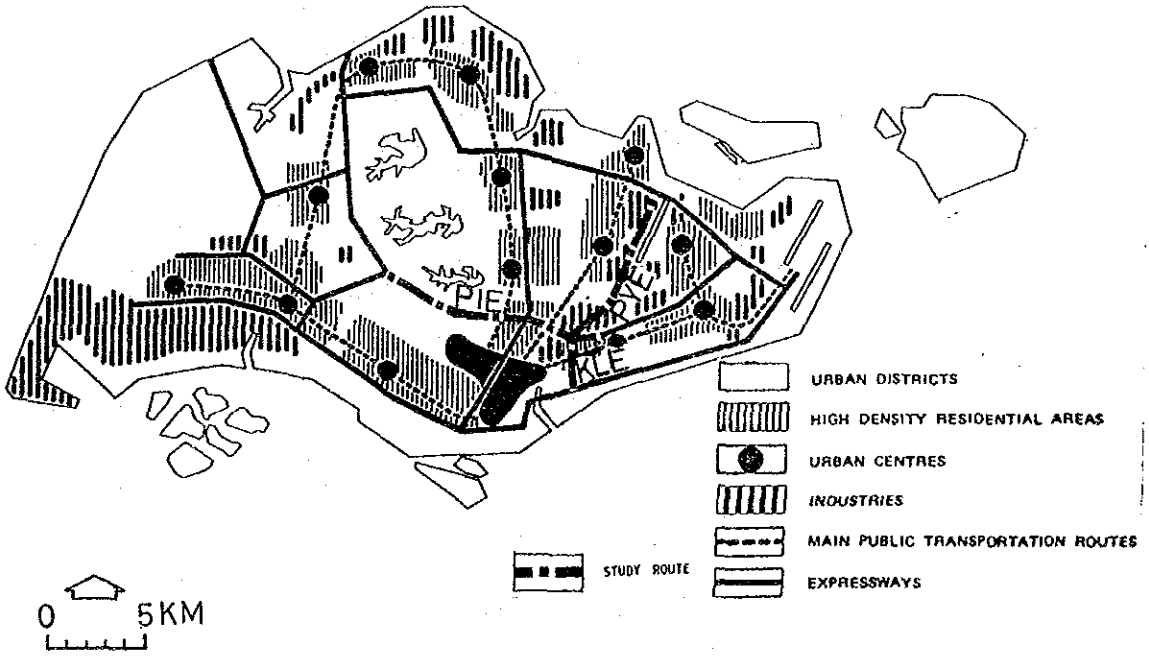


Fig. 3 Revised Concept Plan 1985 Source: Planning Department

2. SOCIO-ECONOMIC CHARACTERISTICS

2.1 Outline of Concept Plan and Master Plan

A Concept Plan had been formulated in 1967 and revised in 1985 as a long range national development plan as shown in Fig.3. The Plan aimed at decentralizing urban functions and optimizing land utilization. The Master Plan was a physical plan and aimed at regulating development projects in compliance with the Concept Plan.

2.2 Socio-economic Indicators

Socio-economic indexes during 1983-1989 were summarized as shown in Table 1.

Table 1 Existing Socio-Economic Indexes

Items	Unit	1983	1984	1985	1986	1987	1988	1989
1.Population	1,000	2,502	2,529	2,558	2,586	2,613	2,647	2,685
2.Employment	1,000	1,168	1,175	1,154	1,149	1,193	1,239	1,277
1) Primary		12	9	8	10	10	6	7
2) Secondary		411	424	340	391	411	444	461
3) Tertiary		744	739	745	747	770	787	808
4) Others		2	3	2	2	2	2	1
3.GDP (1985 (current price)	Bil. S$	36.54	39.57	38.92	39.64	43.39	48.22	52.68
4.GDP/Capita (current price)	1,000 S$	14.6	15.6	15.2	15.3	16.6	18.2	19.6
5.Industrial Product	Bil. S$	36.73	40.05	38.92	38.65	42.61	49.37	55.31
1) Primary		0.33	0.40	0.29	0.22	0.20	0.19	0.19
2) Secondary		13.25	14.94	13.41	14.87	17.76	19.38	19.39
3) Tertiary		23.15	24.77	24.50	26.81	31.40	35.73	35.73
6.Registration of Vehicles	1,000	476.3	491.3	486.8	473.7	471.1	491.8	520.5
1) Private		202.1	217.1	221.3	220.6	222.5	237.8	257.4
2) Taxi		14.8	15.2	15.0	14.0	13.6	13.6	13.8
3) Bus		8.0	8.3	8.7	8.6	8.7	8.9	9.1
4) Truck		105.1	111.3	109.6	105.6	104.9	106.5	113.7
5) Others		146.3	139.4	132.2	124.8	121.3	125.0	126.6

Source : Department of Statistics

3. ROAD TRANSPORT

Road transportation was found to play a major role in Singapore. All the roads in Singapore were designated as national roads and consisted of expressways, arterial roads and primary access and local access roads. The total length of all roads was 2,836 km as of 1989.

Expressways	102 km	(3.6%)
Arterials	512 km	(18.1%)
Primary Access Roads	242 km	(8.5%)
Local Access Roads	1,980 km	(69.9%)
Total	2,836 km	(100.0%)

Expressways had increased by 74 km in length in 11 years since 1978 and major arterial roads also increased by 247 km during the same period. The Singapore Government was found to have put much effort into developing expressways and arterials.

4. SOCIO-ECONOMIC FRAMEWORK

The annual population growth rate of 1.15% as of 1990 was expected to decrease gradually to 0.6% in 2010.

The growth rate of GDP was expected to slow down in future under stable growth conditions the same as developed countries and to be 2% by year 2030.

The share in manufacturing sector was expected to be 30.4% in 1990 and 28.7% in 2010. The share of retail sector would be further reduced to 9.8% in 1995 and 9.3% in 2010. The share of the tertiary sector was expected to reach 59% in 1990, 61.4% in 1995 and 62.0% in 2010.

The future socio-economic indicators were as shown in Table 2.

Table 2 Future Socio-economic Indicators

Items		Unit	1990	1995	2010
Population		1,000	2,708	2,865	3,225
Employment	Total	1,000	1,258	1,387	1,504
	Manufacturing		373	399	431
	Retail		131	136	140
	Others		754	852	944
GDP (1985 Market Price)		Bil.S$	56.37	68.60	112.34
GDP/Capita		1000S$	20.8	23.9	34.8
Registered Vehicle	Total	1,000	553.7	609.7	740.0
	Private Cars		275.1	293.5	335.6
	Taxis		14.9	15.8	17.7
	Buses		9.2	9.7	10.9
	Goods Vehicles		121.6	148.0	209.0
	Motor Cycles		126.9	135.0	154.8
	Others		6.0	7.3	11.9

Source : Study Team

5. FUTURE TRAFFIC VOLUME FORECAST

The LTS Report (Land Transport Study : 1986 Ministry of Communication and Information) was used for traffic volume forecast.

5.1 Zoning

MTZ (Mass Transit Zones) was used for zoning. Singapore was divided into 17 zones consisting of 410 sub-zones.

5.2 Future Traffic Volume

The desired lines for vehicle traffic between zones were analyzed as shown in Fig.4. The forecasted traffic volume were as shown in Fig.5 in peak hour condition, ie., Morning and Evening Peak Hours.

6. FORMATION AND STUDY OF SCHEMATIC ALTERNATIVES

6.1 Necessary Number of Lanes

Traffic volume capacities of sections were determined, as follow;

- Expressway : 2,200 vehicles/lane/hour
- Slip Type Ramp : 1,800 vehicles/lane/hour
- Loop Type ramp : 1,600 vehicles/lane/hour

Necessary number of lanes on the PIE was four(4) for one direction; however, the stretch between the interchanges of PIE/Thomson and PIE/CTE needed five(5) lanes because the ON and Off ramps were very close.

As to the KLE and PYE, the whole section was found to need a maximum of six(6) lanes for both directions.

The number of lane for ramps were analyzed for each interchange also.

6.2 Alternatives for PIE

The location and congested environ of PIE limited the formulation of alternatives in horizontal alignment. Meanwhile, various alternatives in vertical alignment were conceived such as at-grade widening, viaduct and semi-depressed structures.

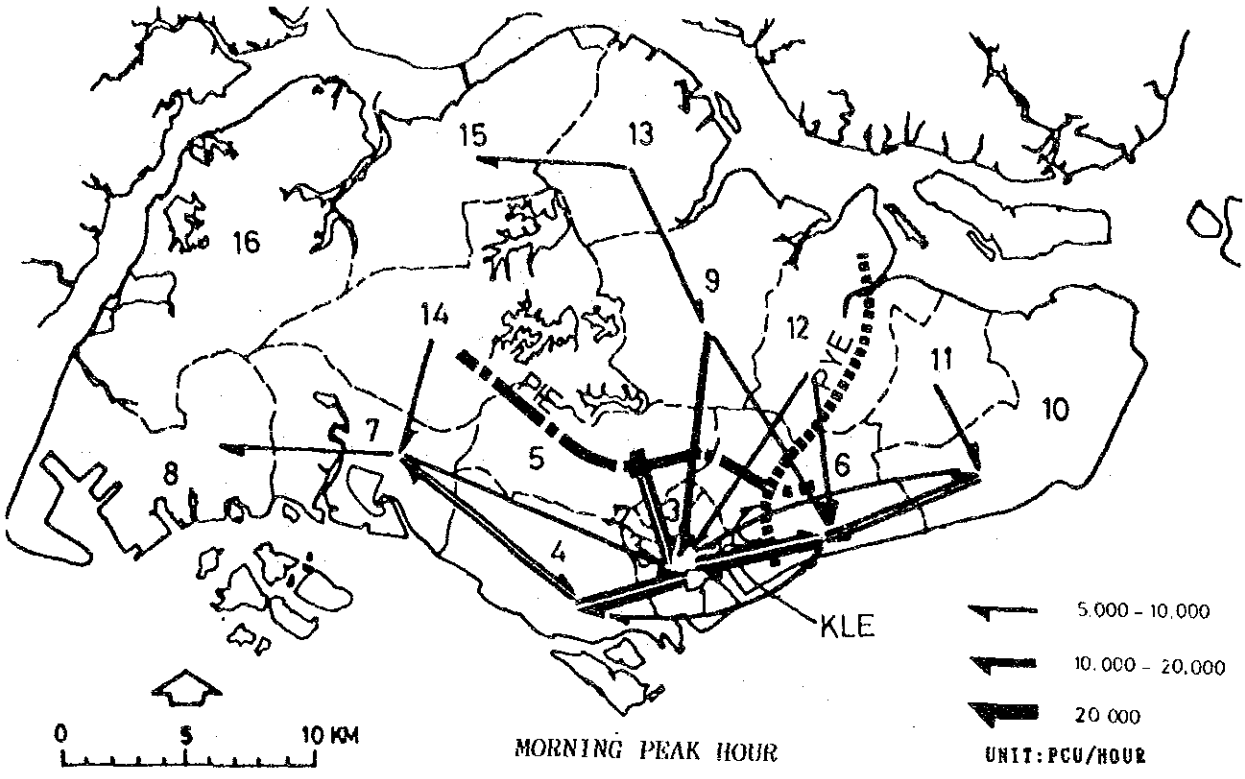
Underground idea was explored but aborted owing to sub-grade obstacles. The following alternatives, as shown in Fig.6 and Fig.7, consequently were proposed for the schematic design in the Phase-I Study and investigated accordingly.

(1) At-grade widening scheme
- One lane widening on both sides of the existing PIE : I-1-a
- One lane widening on both sides of the existing PIE with separator between fast lane and slow lane. : I-1-b
- Removal of the off ramp at the PIE/Toa Payoh IC and oN ramp at the PIE/Kim Keat IC towards Changi Airport: I-1-c
- In addition to the above scheme, the transfer of the oN ramp at the PIE/Toa Payoh IC towards Jurong to the location at the PIE/Kim Keat IC. : I-1-d

(2) Viaduct scheme
- New construction of viaducts between the interchanges of PIE/CTE and PIE/Mt. Pleasant Interchange. : II-1
- New construction of viaducts between the interchanges of PIE/CTE and PIE/BKE. : II-2

6.3 Alternatives for KLE

The location of interchanges at KLE/PIE and KLE/ECP was found



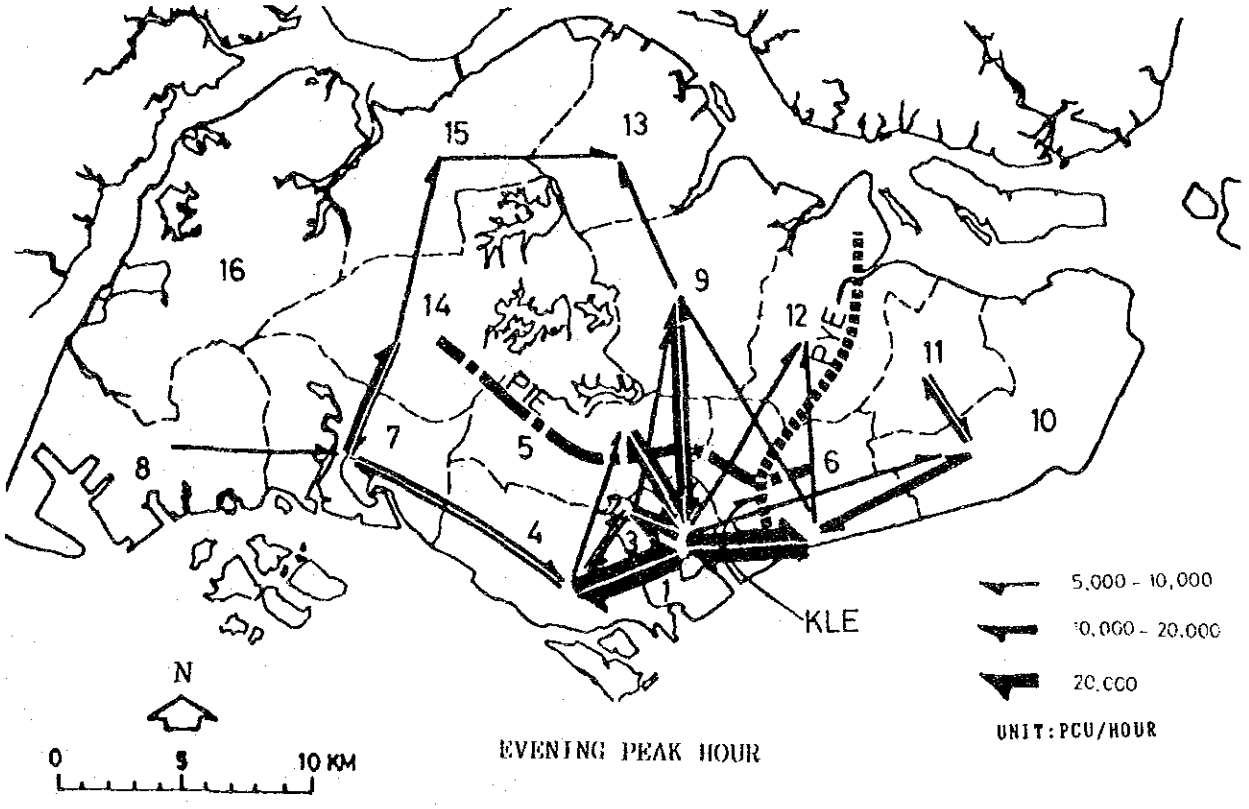


Fig. 4 Desired Lines on 2010

Source : Study Team

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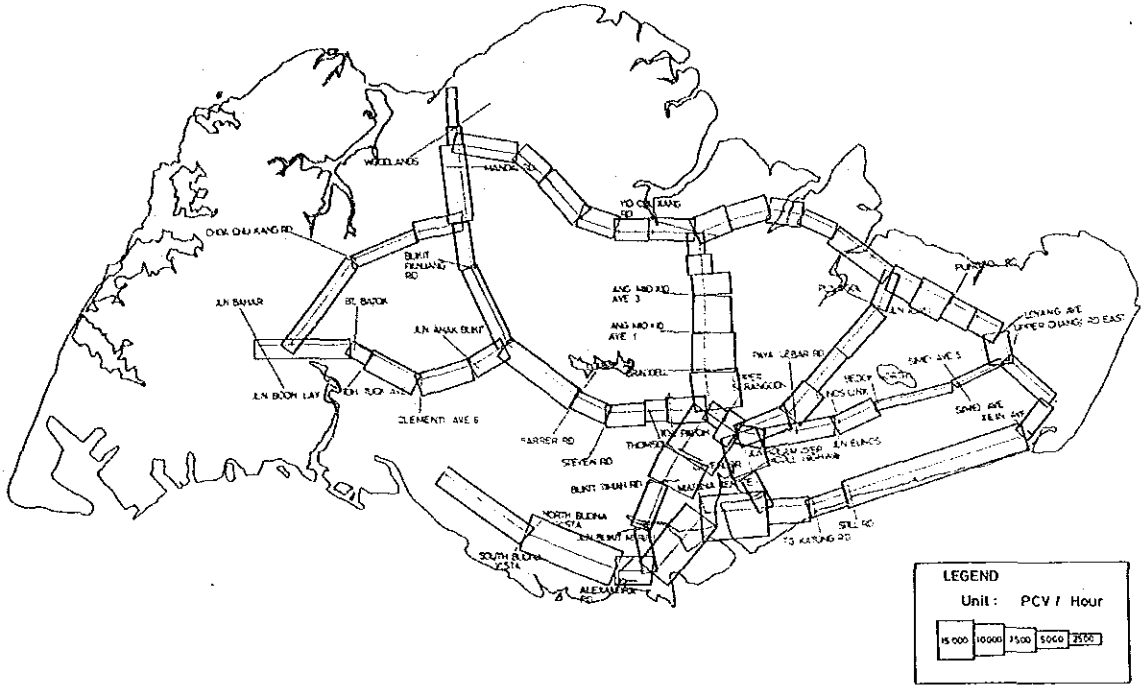
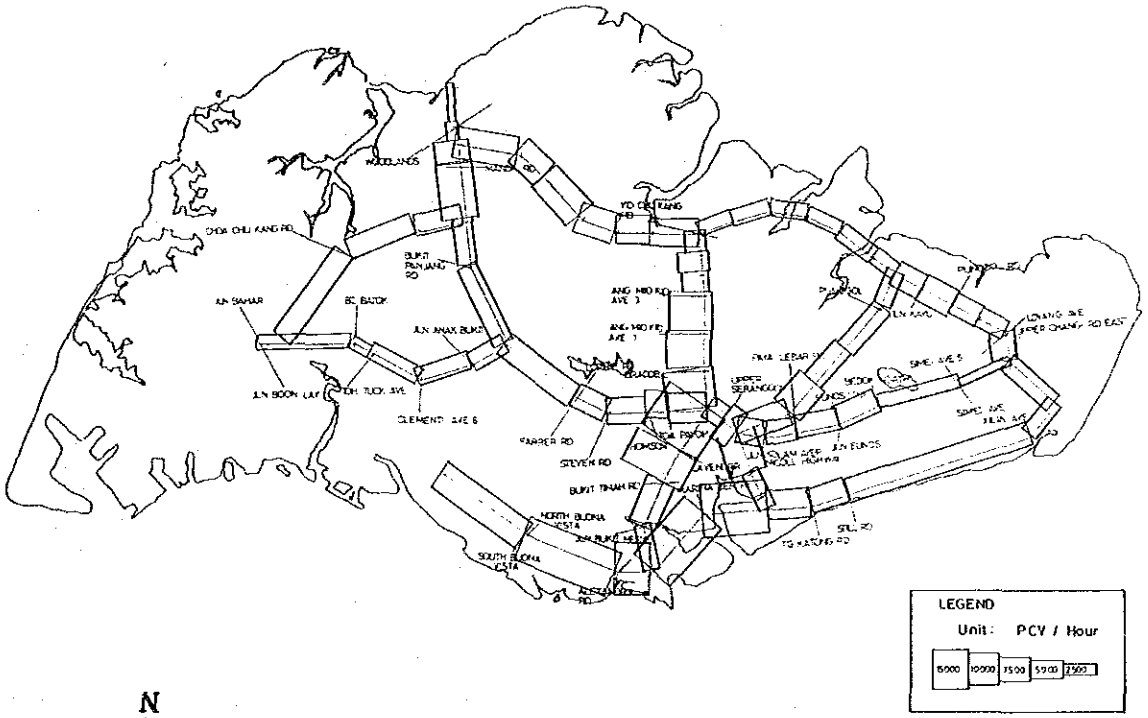


MORNING PEAK HOUR



EVENING PEAK HOUR

Fig.5 Future Traffic Volume in 2010

Source: Study Team

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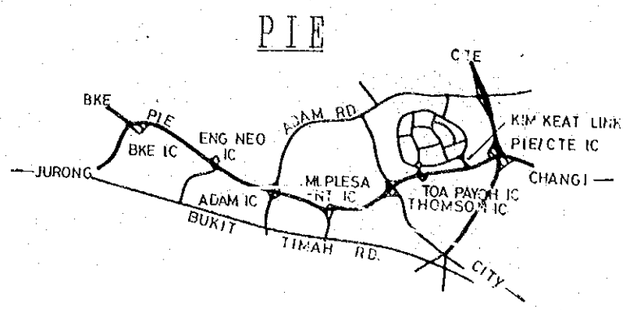


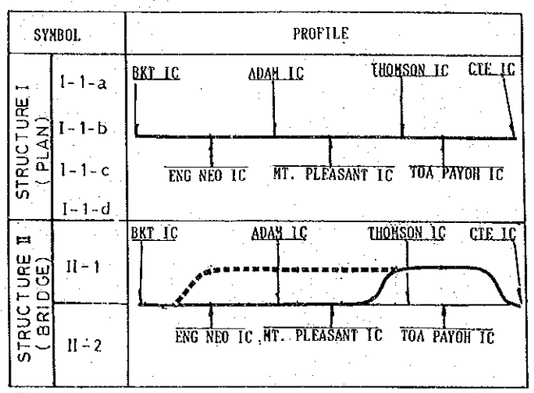


Fig. 6 Alternatives for Pan Island Expressway

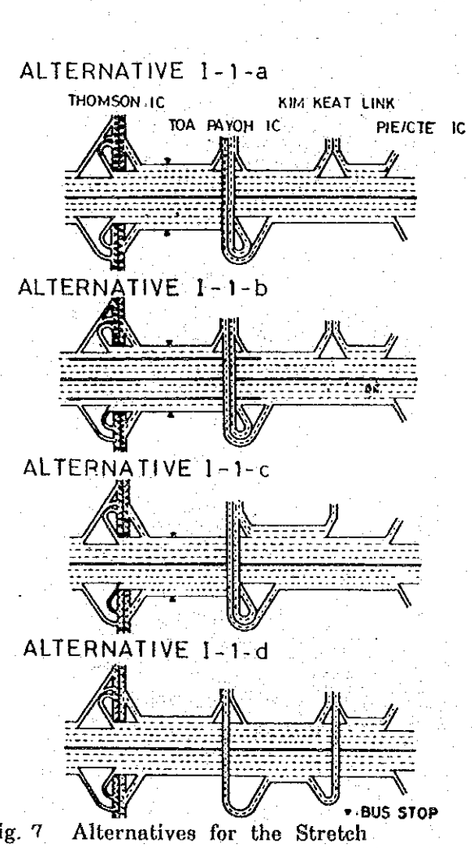
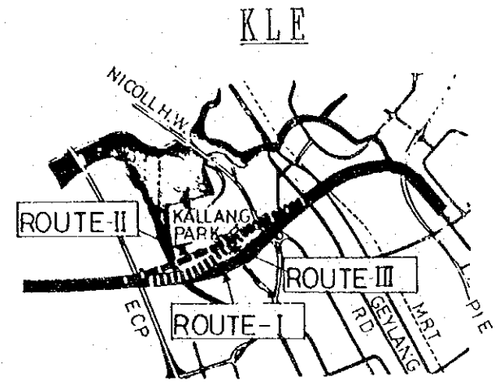


Fig. 7 Alternatives for the Stretch between Thomson IC & PIE/CTE IC



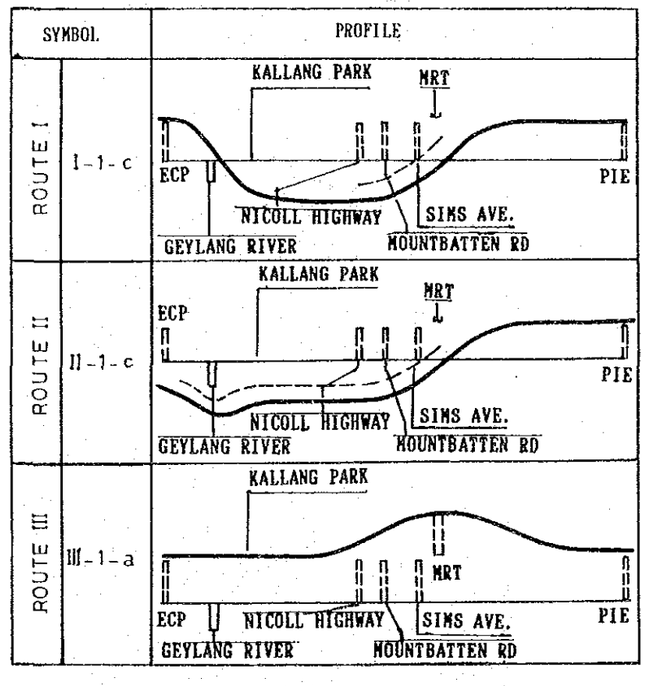
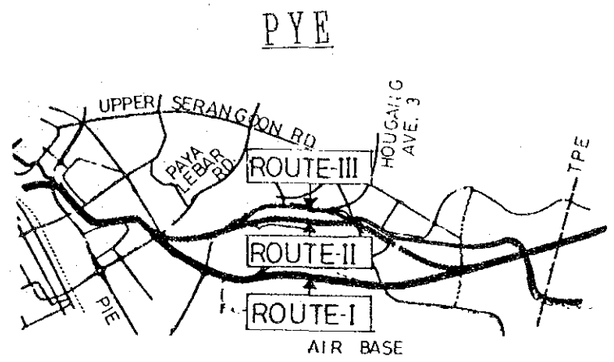


Fig. 8 Alternatives for Kallang Expressway



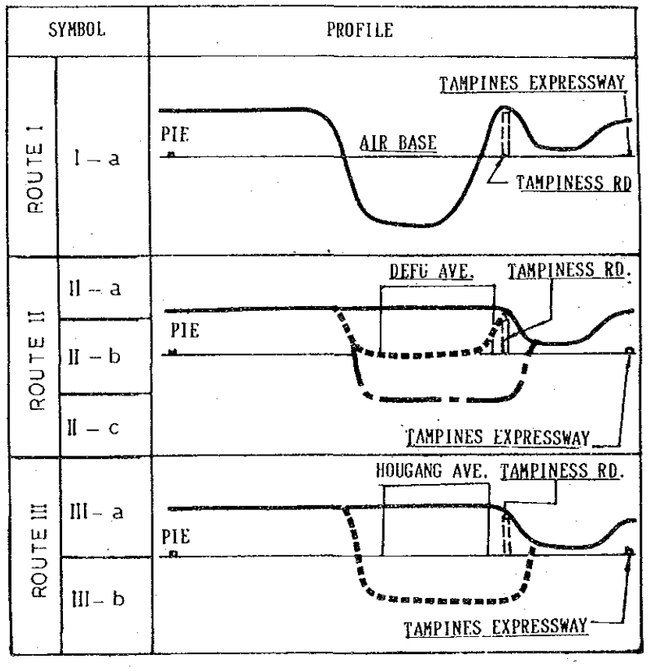


Fig. 9 Alternatives for Paya Lebar Expressway

already to be almost fixed, and available land in between for horizontal route was very limited within a narrow area. There were a lot of crossings between the ECP and PIE, eg. Geylang River, Kallang Park, Nicoll Highway, Mountbatten Road and MRT. Viaduct and tunnel alternatives were adopted. Three alternatives as shown in Fig.8 were selected and the schematic designs were carried out.

6.4 Alternatives for PYE

As to the PYE, location of route was selected at the Air Base, Defu Avenue and Hougang Avenue; and having possibilities of at-grade, viaduct and underground structures, six alternatives combining these, as shown in Fig.9, were formulated and investigated.

7. EVALUATION OF SCHEMATIC ALTERNATIVES

Items for alternative evaluation were as listed below. Weighting and ranking methods were adopted for comprehensive evaluations of alternatives.

(1) Under construction
- Technical aspect
  - Traffic : Capacity
  - : Accessibility
  - Structure: Construction technique
  - : Construction period
- Economic aspect : Land acquisition cost
  - : Construction cost
- Social aspect : Noise and vibration

(2) During Operation
- Technical aspect
  - Traffic : Capacity
  - : Traffic safety
  - : Provision of rescue activity during accident
- Economic aspect : Maintenance cost (Ventilation & drainage)
- Social aspect : Noise and vibration
  - : Aesthetics
  - : Community separation
  - : Possibility of future extension
  - : Security of the Air-base

(1) PIE

The alternatives with viaduct construction did not have a remarkable advantage, even on the viewpoint of traffic management. Meanwhile among the at-grade widening alternatives, the Alternative I-1-d was considered to be the most superior. The scenario for future improvement of the PIE was formed as described below. (see Fig.7)

The Alternative I-1-b was recommended until around the year 2000 when traffic volume would reach capacity. After which, the Alternative I-1-a was recommended because of the flexibility in lane usage. When the traffic volume should increase even more, then, as shown in Fig.7

for the Alternative I-1-d, a new over-bridge would have to be constructed at the PIE/Kim Keat Interchange to ease the weavings at the interchanges between PIE/Thomson and PIE/Toa Payoh.

(2) KLE

The Alternative III-1-a with the scheme of viaducts had the highest total score among the three alternatives, followed by the Alternative I-1-c. As such, the Study Team recommended two alternatives to proceed to the next preliminary design stage.

(3) PYE

Three alternatives, ie., the Alternatives I-a (Tunnel under the Air Base), II-a (Viaduct over Defu Avenue) and II-b (At-grade widening on Defu Avenue) were selected. The Study Team, however, considered that there might be advantages in shifting the alignment of the Alternative II-b to run alongside the fence of the Air Base (Green Belt) rather than along Defu Avenue. This was examined in the Phase-II Study.

8. PRELIMINARY DESIGN

8.1 Design Conditions

(1) Design Standard

Different design speed was used for each type of roads as described below.

Expressway	:	80 km/h
Ramp connecting expressways	:	60 km/h
Ramp of slip road type	:	50 km/h
Ramp with loop section	:	40 km/h

For structure designs, the design standards in Singapore and BS5400 were used.

The standard cross sections were as shown in Fig.10.

(2) Subsoil Condition

a. Geological profile of the Project area

Along the PIE, top soil was found to be soft clay. Second layer, i.e, Jurong Formation, changed its depth along route.

Along the KLE, the soil was found to be very soft underlaid by strata in varying depth.

Along the PYE, the subsoil was firm with a shallow top soil.

b. Foundation of viaduct and roadway

Pile foundation was recommended for viaducts and bridges. Bearing strata should be the Old Alluvium.

c. Study on materials

Abundant shale rock in the Jurong Formation was found to be suitable as sub-base material to give CBR value more than 40%. Weathered granite rock and Old Alluvium could meet the required CBR for road

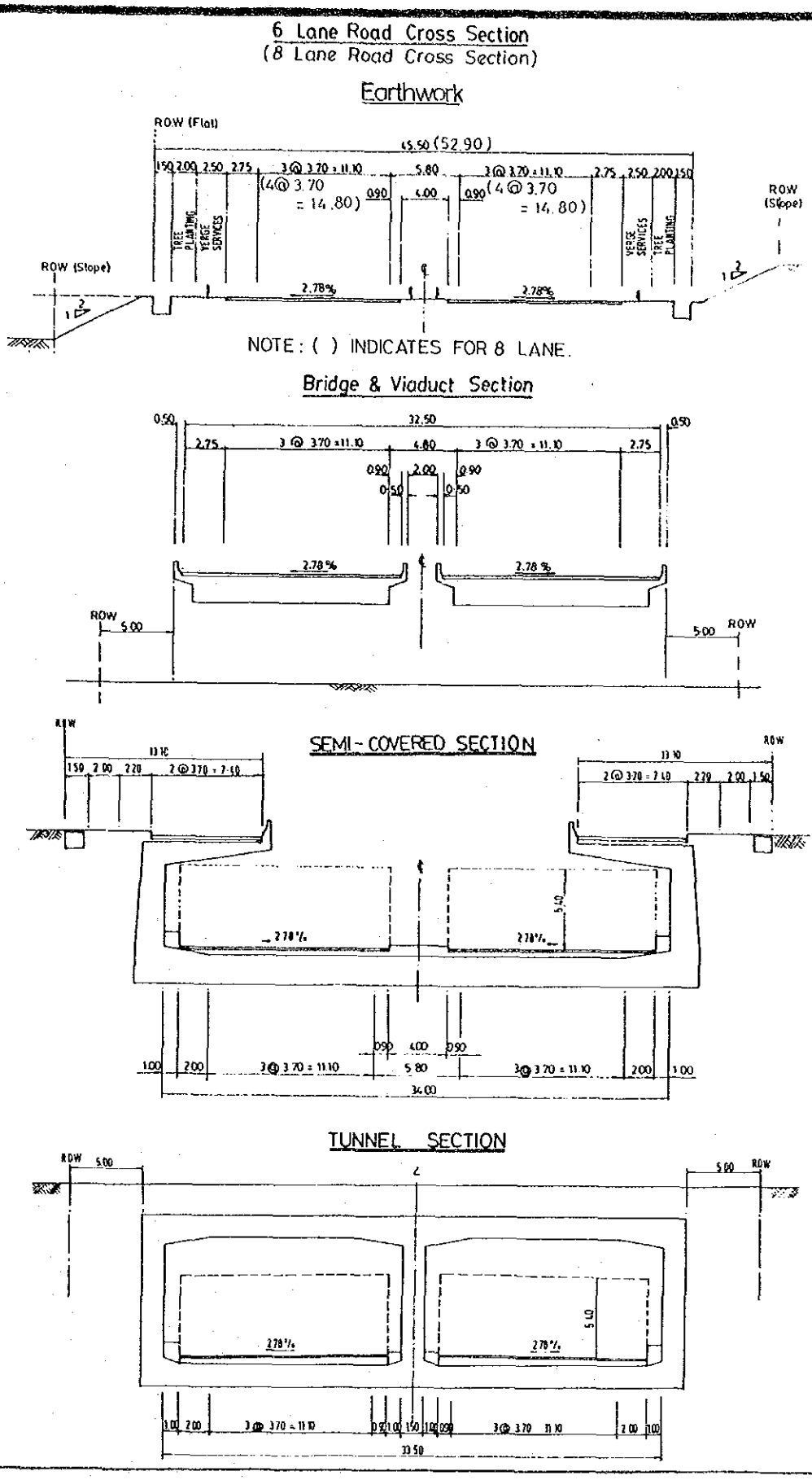


Fig. 10 Typical Corss Sections for Expressways

Source : Study Team

subgrade.

(3) Hydrological Condition

High water level(HWL) was stipulated based on the statistical record of tidal level. HWL was 101.75m for Geylang River and 102.05m for Serangoon River. Free board was required 0.75m above HWL.

8.2 Pavement Structure

Asphalt pavement was recommended in line with the Singapore practice.

8.3 Preliminary Design of PIE

Study result was presented in Fig.11.

(1) Route Alignment

A widening of one lane at each side of existing road was recommended for the sections between the interchanges of PIE/BKE, PIE/Adam and PIE/Mount Pleasant since there was not many major control points and available space alongside.

The PIE at the PIE/Mount Pleasant Interchange was added with four new lanes on the north side of the existing road to improve the alignment at this point. Moreover the improvement of the bridge was found to be not easy.

Some sections of PIE were found not very ideal in view of vertical alignment but were practically acceptable as they were. The Study Team did not recommend improvement on vertical alignment in order to avoid huge amount of work on structures and interchanges and also disturbance on traffic should they be altered.

(2) Interchanges

a. PIE/BKE Interchange

Two lanes on all the ramps would be required. Those which did not meet this condition were recommended to be improved by adding one more lane on the ramp.

b. PIE/Eng Neo Interchange

At present, only the off ramp of east bound was found to have two lanes but all the others to have one lane each. The off ramp of the west bound would need two lanes in future as recommended. To increase the length of acceleration and deceleration lanes and to decrease the angle of merge were also recommended.

c. PIE/Adam Interchange

There were found to be deficiencies in this interchange such as inadequate acceleration lane and S-curve in the off ramps. Continuous merging from the ramps into the main through flow was improved by an introduction of merging lane which would enable ramp traffic flows to merge first prior to entering the expressway.

d. PIE/Mount Pleasant Interchange

This interchange was found to have traffic safety operation

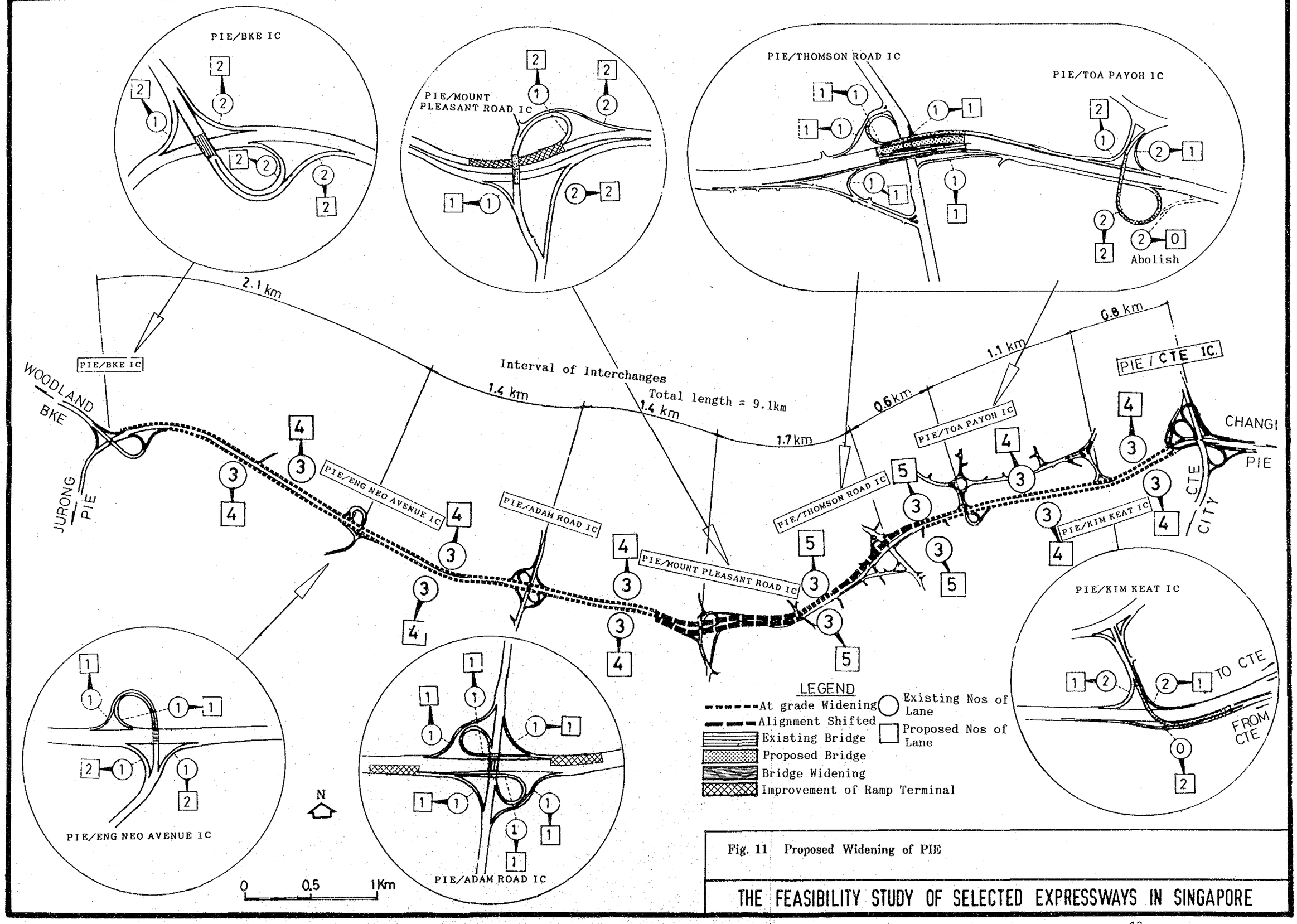


Fig. 11 Proposed Widening of PIE

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problems because the main expressway had a tight 300m radius curve and on and off ramps for the east bound were situated at the eastern side of the flyover. The off ramp was recommended to be moved to the western side of the flyover and the radius of expressway was improved to 400m accompanied by additional lanes. Adequate deceleration lane length for the speed from 80km/h to 40km/h were provided.

e. **PIE/Thomson Interchange to PIE/Kim Keat Interchange**

There were found to be four interchanges in a short distance between the interchanges of PIE/Thomson and PIE/CTE. This created problems because of heavy traffic flow, continuous merging and diverging, and existence of bus stops. The sections of both east and west bound between the interchanges of PIE/Thomson and PIE/Toa Payoh, and the east bound between the interchanges of PIE/Kim Keat and PIE/CTE showed worst merging of traffic. The existing traffic flow at the roundabout at the north of the PIE/Toa Payoh Interchange was 7,000 at the peak hour which was almost the capacity of the roundabout.

Taking into account all the prevailing problems, the final alternative was recommended. The major points were;

- Add new four lane at the north of PIE/Thomson Interchange.
- Introduce a system of slip/service roads to separate traffic flows.
- Rearrangement of ramps to ensure capacity and smooth flow of traffic.

(3) Structures

All the structures of PIE except at the PIE/Toa Payoh Interchange were proposed to be retained. Where necessary, new structures were added as improvements. The flyover of PIE/Toa Payoh Interchange was recommended to be demolished due to insufficient head room clearance, and to cope with proposed improvement.

8.4 Preliminary Design of KLE

(1) Route Alignment

The control points for the route selection were the proximity to ECP/Fort Road Interchange and the Benjamin Sheares Bridge, and the rows of medium-rise houses east of Geylang Lorong 4.

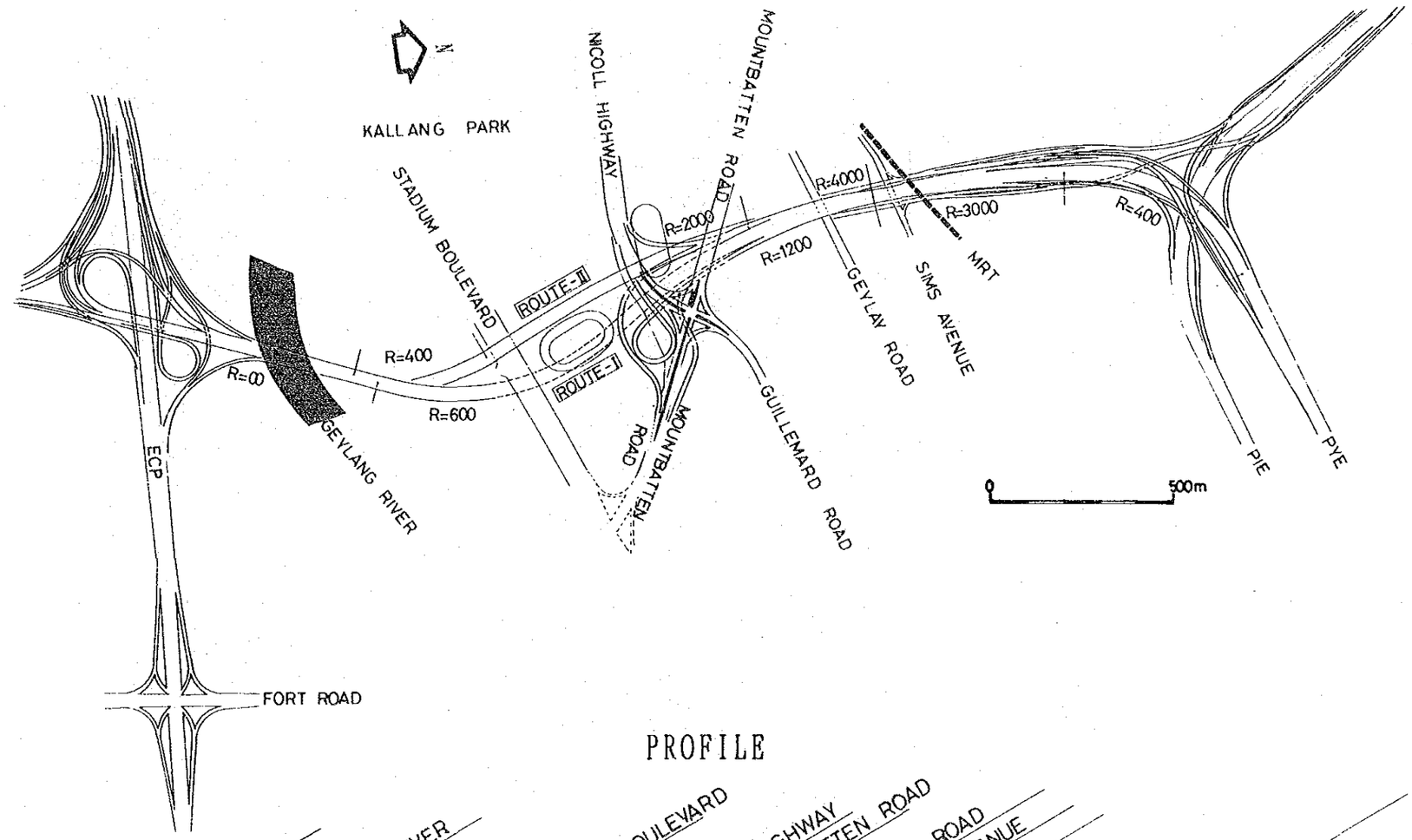
General information on route alignment of KLE was as presented in Fig.12.

a. **Route-1 Alternative**

The Route-I (Tunnel Alternative) was conceived to pass through the ECP and Geylang River by viaduct/bridge; the Kallang Park by a tunnel; the Nicoll Highway, Sims Avenue and MRT by semi-depressed; and the PIE by a viaduct.

A radius of 600m and a gradient 3 % were adopted taking traffic safety into consideration. The tunnel portal was consequently set further back. Many points were taken into consideration such as the height of right bank of Geylang River; tunnel section which had to be deeper than 10.5m below ground level; pier and foundation of MRT; crossing at the PIE; and smoother gradient of road at tunnel and interchanges.

PLAN



PROFILE

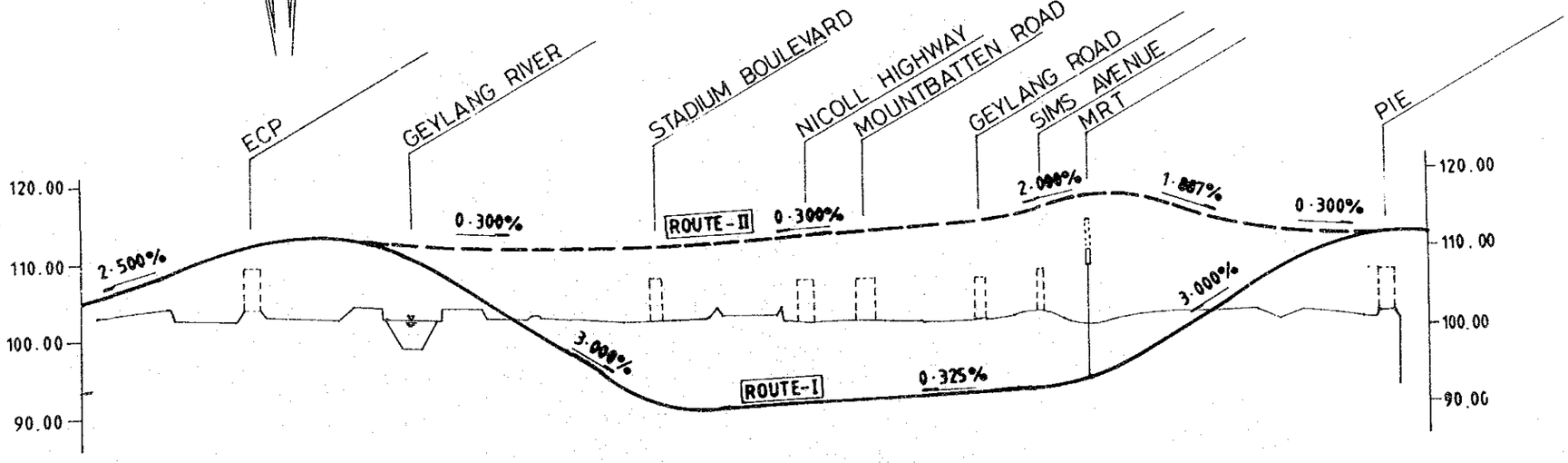


Fig. 12 Route Alternatives for KLE

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b. Route-II Alternative

The Route-II (Viaduct Alternative) was conceived to use viaduct all the way through between the ECP and PIE.

A horizontal alignment to optimise land use was adopted. A vertical alignment was planned to secure sufficient vertical space for the park and to be high enough over MRT lines.

(3) Interchange

Proposed interchanges were as shown in Fig.13.

a. KLE/ECP Interchange

Since the location of KLE/ECP Interchange was proposed to be in between the ECP/Fort Road Interchange and Benjamin Sheares bridge, there were some problems to be solved such as the distance for weaving with the former interchange and difficulty in extending the Interchange into the bridge proper.

The minimum radius for a design speed of 60km/h was 125 m. Considering minimization of land requirement, tighter radius of 60m was used in the off ramp of the east bound together with sufficient deceleration lane length. Approximately 3.5 ha of land was saved. The distance between the ramps of ECP/Fort Road Interchange and this was 450m and a running speed of 40km/h could be achieved even in the weaving section.

b. KLE/Nicoll Interchange and KLE/PIE/PYE Interchange

KLE/Nicoll Interchange was proposed to be located near Nicoll Highway, Mountbatten Road, Sims Avenue and Geylang Road. The distance in between the interchanges of KLE/Nicoll and KLE/PYE/PIE was so small that those two interchanges were studied as one interchange. (see Fig.13) Priority of access services was studied and applied.

An alternative allowing no merging along ramps was recommended. The other alternative allowing merging had simple structures. However, there were disadvantages such as higher possibility of accidents and slower traveling speed of less than 30km/h.

The alignment of KLE/Nicoll Interchange was designed to satisfy the expressway standards. However, the interchange was constrained by very tight horizontal and vertical alignment and very close diverging and merging. Traffic safety measures were recommended for operation.

(4) Structures

Preliminary design included bridge, viaduct, tunnel, retaining wall and depressed trough, taking into account locations, economy, construction method, and aesthetics.

Crossings of rivers and major roads where long span was required, were planned with cast-in-place prestressed concrete bridges.

Viaduct passing through city area was recommended to use standardized precast beams for economy and aesthetics. In the design of bridge and viaduct, aesthetic viewpoint was emphasized.

Tunnel and depressed trough were studied where neither viaduct nor ground level roadway was possible. Main tunnel at the KLE was 500m long under Kallang Park in the Route-1 Alternative. Tunnel planning

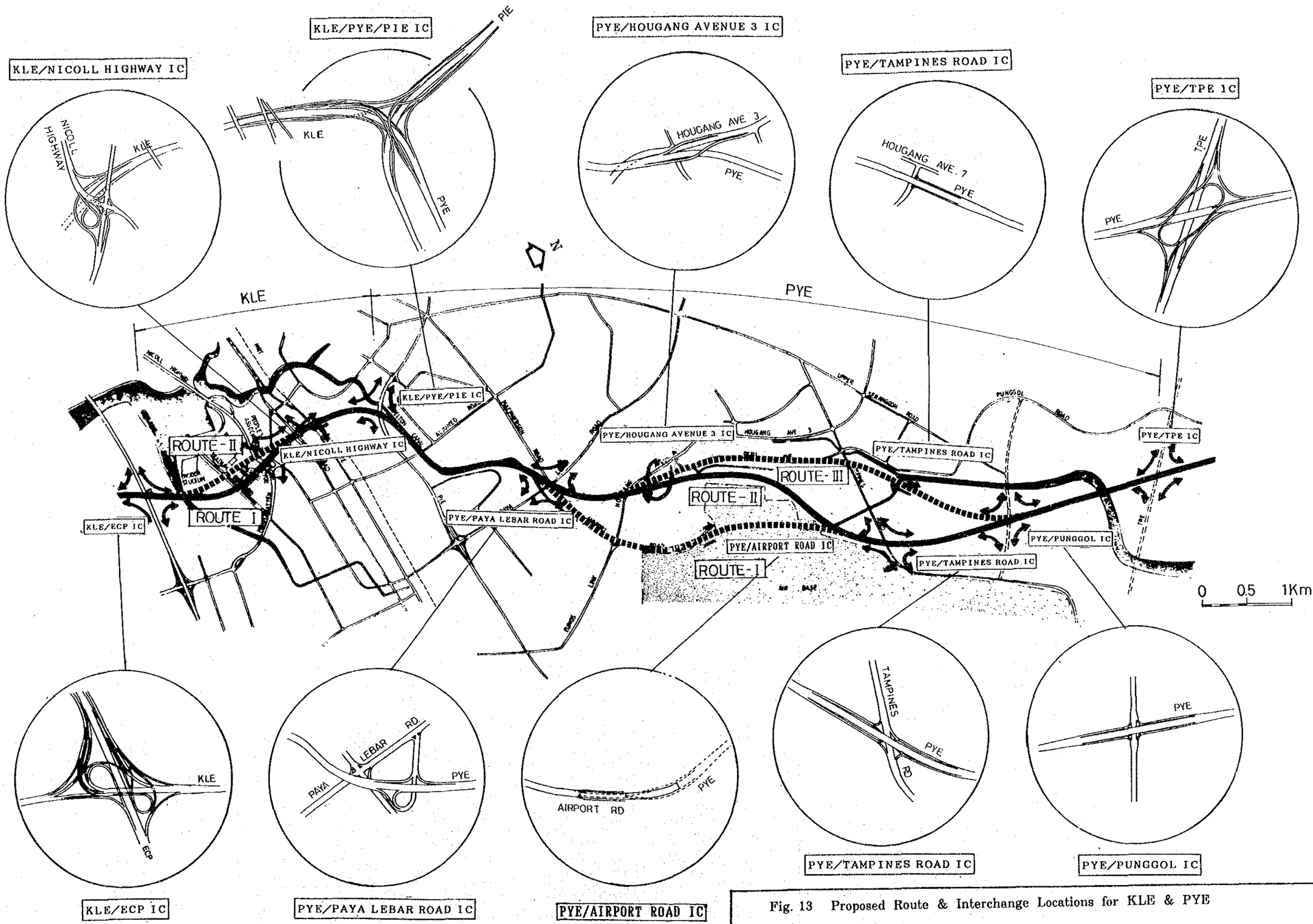

Fig. 13 Proposed Route & Interchange Locations for KLE & PYE

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included ventilation and emergency facilities.

Two alternatives were studied and designed with the result as shown in Fig.14. Length of structure was as listed in Table 3.

Table 3 Length of Structures for KLE

Alternative	Viaduct /Bridge	At-Grade /Approach	Depressed/ Trough	Tunnel	Total Length
Route-I	1280m	245m	1410m	495m	3430m
Route-II	3400m	0	0	0	3400m

8.5 Preliminary Design of PYE

(1) Route Alignment

The PYE was proposed to be approximately 9 km long. It was conceived to start at the PIE as an extension of the KLE, to cross Paya Lebar Road and Tampines Road, and to end at the TPE.

General information for route alignment was as summarized in Fig.15.

Medium to high rise flats and schools were found between the PIE and Paya Lebar Road. A radius of 300m, which was an absolute minimum value, was used to avoid such facilities. The formation height was set at 10 to 12m above ground taking into consideration the aesthetics.

There were three alternatives between Paya Lebar Road and Tampines Road.

a. Route-I Alternative

The Route-I Alternative was proposed to pass Airport Road by a viaduct and Air Base by a tunnel. Kim Chuan treatment plant, structures at the Air Base and sewage pipeline at the north were avoided. The formation level was kept to be more than 12.5m and the maximum gradient in the tunnel was 3 percent.

b. Route-II Alternative

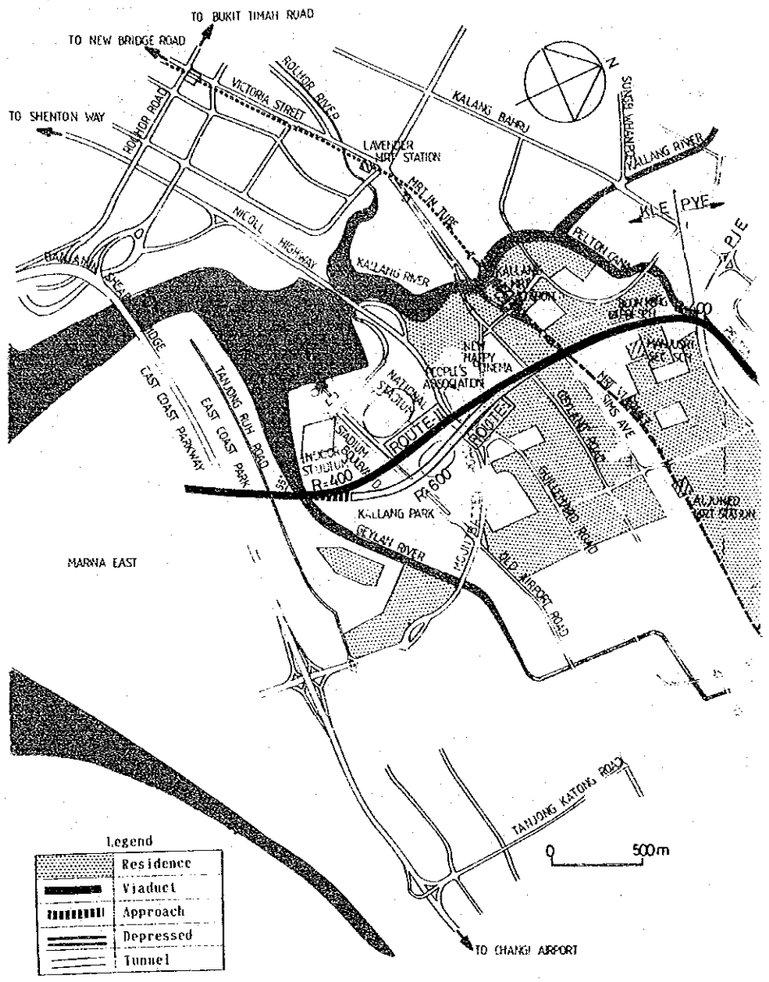
The Route-II Alternative was proposed to swerve from the Route-I before Paya Lebar Road, to pass through the north of the Tai Seng industrial estate, to cross Hougang Avenue 3 and the green belt of the Air Base; then to join the Route-I before Tampines Road. The formation level at the green belt was kept at the same level as the Air Base. The SBS bus depot site was slightly affected but the operation could be adjusted.

c. Route-III Alternative

The Route-III Alternative was proposed to swerve from the Route-II before Hougang Avenue 3, to pass over Defu Avenue, to cross Tampines Road and Serangoon River and then to join the Route-I at the planned location of the PYE/Punggol Interchange. The effects on operation of the SBS bus depot was kept to minimum. The formation height over Defu Avenue was more than 12.5m.

The section between Tampines Road and the TPE was planned so as to cross Serangoon River at right angle.

PLAN



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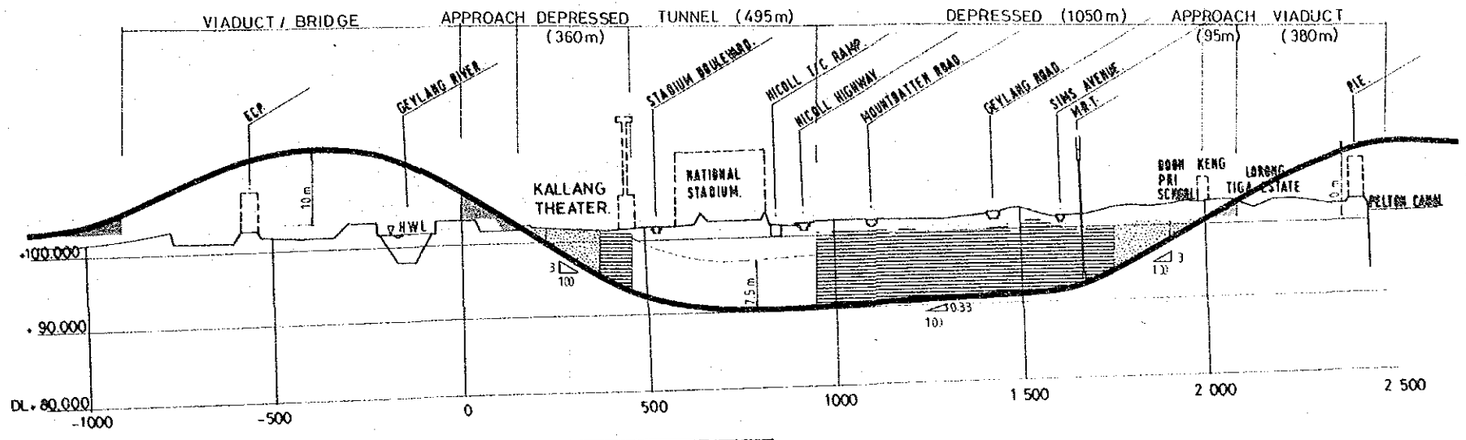
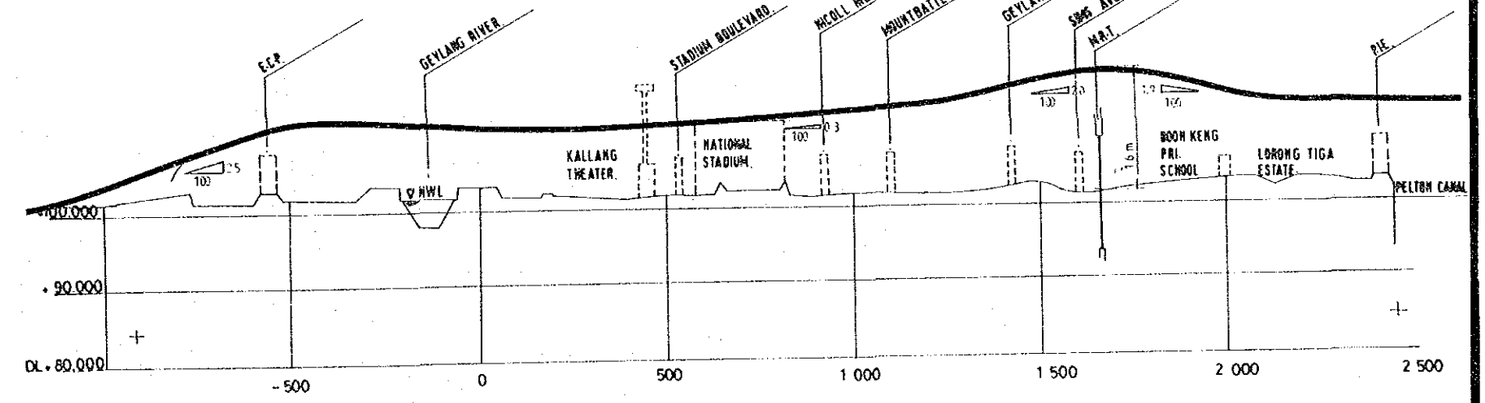
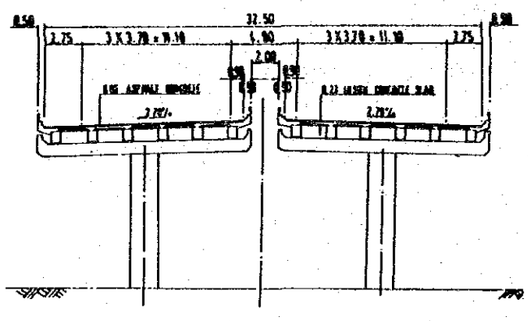


ROUTE-I

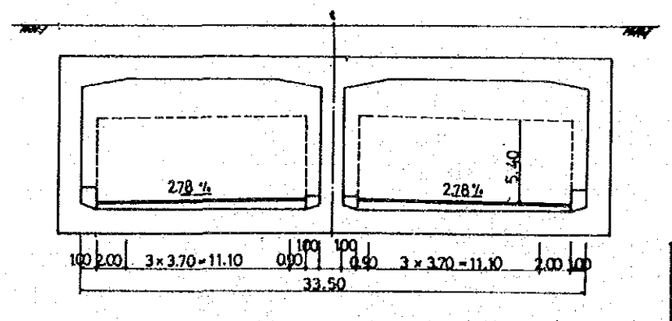


ROUTE-II

CROSS SECTION



VIADUCT SECTION



TUNNEL SECTION

LEGEND:

- EMBANKMENT RETAINING WALL
- TUNNEL
- U SHAPED TROUGH
- SEMI COVERED TROUGH

Fig. 14 Structure Planning for KLE

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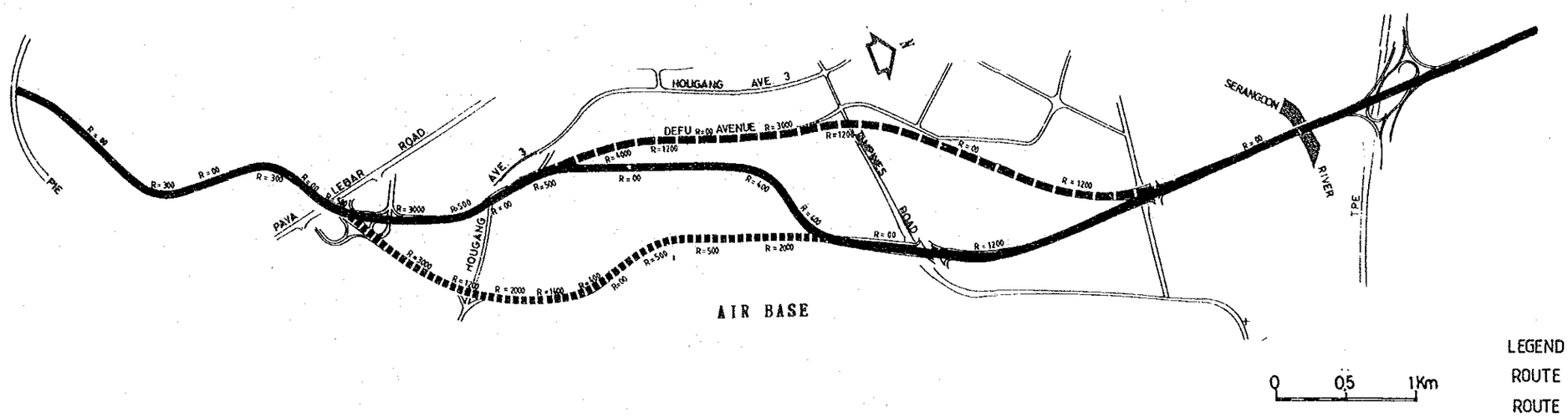
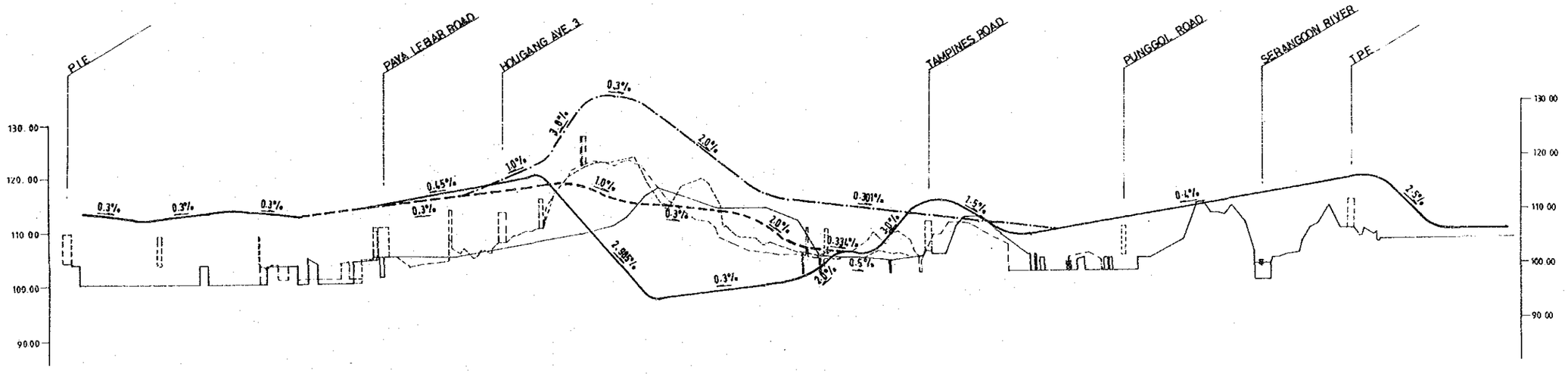
PLAN



LEGEND :
ROUTE I
ROUTE II
ROUTE III

PROFILE



LEGEND :
ROUTE I
ROUTE II
ROUTE III

Fig. 15 Route Alternatives for PYE

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(2) Interchanges

The proposed interchanges were as shown in Fig.13.

a. PYE/Paya Lebar Road Interchange (Routes-I, II and III)

This interchange was very important because of traffic demand from all the directions of KLE, PIE and TPE.

There was no loop ramp for the Route-I Alternative and the radius was more than 80m. The problem with this was that two new junctions were introduced spaced only 250m apart.

For Route-II and III Alternatives, type B trumpet was recommended to secure enough weaving length as well as distance between two signalized junctions. The radius of loop was 45m.

b. PYE/Airport Road Interchange (Route-I)

This interchange was proposed at Airport Road where the PYE viaduct was to meet the tunnel. It would serve only the traffic going to and coming from PYE/TPE directions. A diamond type was recommended to avoid the Kim Chuan sewerage plant and Air Base facilities and to use minimum lands.

c. PYE/Hougang Avenue Interchange (Route-II and III)

This interchange was recommended to pair up with the PYE/Tampines Road Interchange for servicing the traffic demand of Hougang area. It was a half diamond type. The SBS bus depot and civil defence sites were considered to be control points.

d. PYE/Tampines Road Interchange (Routes-I, II and III)

Diamond type was recommended for all the alternatives.

e. PYE/Punggol Interchange (Route-I, II and III)

This interchange was recommended to have services with the planned road from the future Kangkar Newtown, and to use a diamond type.

f. PYE/TPE Interchange (Routes-I, II and III)

For this interchange, two types were studied, namely semi-clover and turbine. The semi-clover type was recommended because of smaller total length of structure; better adaptability for future allocation of structures; and lesser land take.

(4) Structures

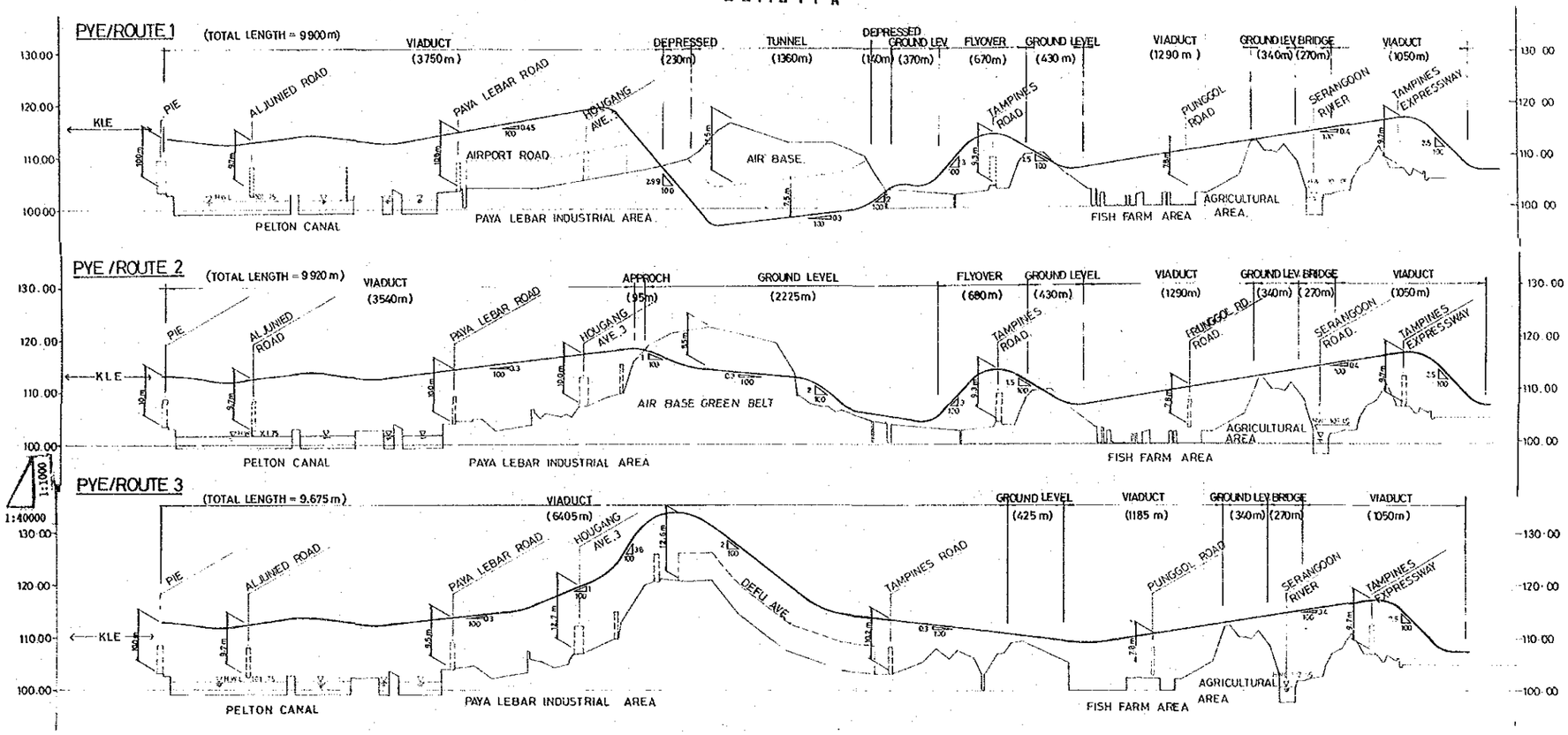
Structures were studied similar to that done for the KLE.

Three alternatives were studied and designed with the result as shown in Fig.16. Length of structures were as summarized in Table 4.

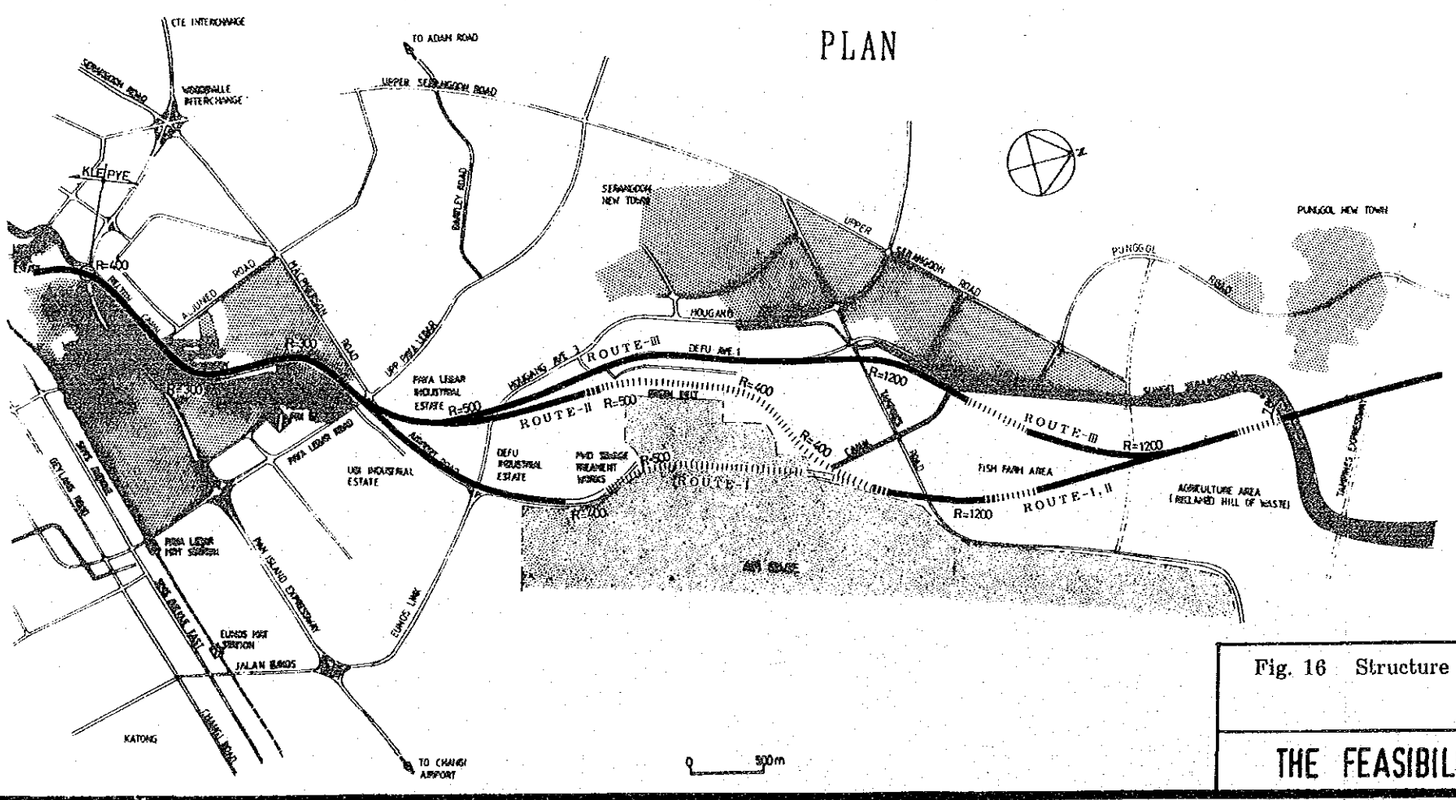
Table 4 Length of Structures for PYE

Alternative	Viaduct /Bridge	At-Grade /Approach	Depressed/ Trough	Tunnel	Total Length
Route-I	7030m	1140m	370m	1360m	9900m
Route-II	6830m	3090m	0	0	9920m
Route-III	8910m	765m	0	0	9675m

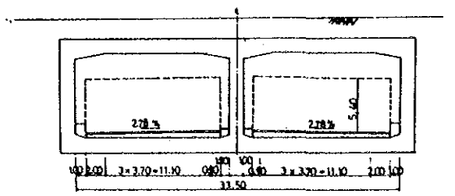
PROFILE



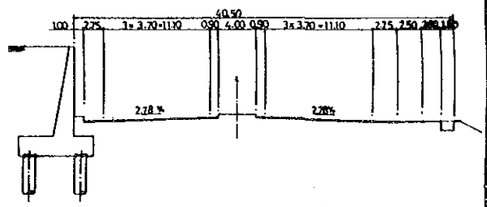
PLAN



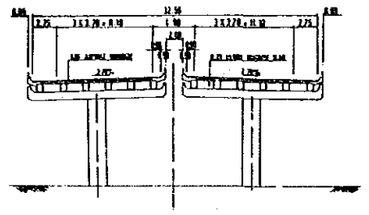
CROSS SECTION



TUNNEL SECTION



GROUNDLEVEL SECTION



VIADUCT SECTION

Legend

	Residence
	Viaduct
	Approach
	Ground level
	Depressed
	Tunnel

Fig. 16 Structure Planning for PYE

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8.6 Construction Schedule

The stages of works were studied based on the following conditions;

(1) The standard work procedure in accordance with the capability of ordinary construction machineries.

(2) Some past similar construction projects.

(3) The construction sections of each expressway were divided by the working contents, work scale, the developing situation on each road site and construction plans in Singapore.

Each construction section would need maximum of three years, determined using the above conditions.

9. COST ESTIMATE

9.1 Construction Cost

The construction cost was estimated using calculated construction volume resulting from preliminary designs of each alternatives. Construction cost was as shown in Table 5.

9.2 Land Acquisition and Compensation Cost

Data for land acquisition and compensation costs calculation was obtained through PWD and used for estimation. Results were as summarized in Table 6.

9.3 Maintenance and Administration Cost

The maintenance and administration cost was different depending on type of road. Costs for concrete bridge were about the same as the at-grade expressways. Costs for tunnel section were 8 times that of at-grade section.

Since there was no such available data for tunnel in Singapore, these costs were calculated using Japanese data. The ratio of maintenance and administration costs to construction cost was as summarized in Table 7. Cost estimates in Table 8 for ordinary years were calculated based on these ratios.

10. ECONOMIC ANALYSIS

10.1 Methodology

The main purpose of economic analysis was to evaluate the effects of the expressway projects from the viewpoint of economic resources. The analysis also aimed at determining the feasibility of alternative projects recommended by the Study Team.

The economic analysis was conducted by comparing the social benefits expected to be generated by the improvement of the road network

Table 5 Construction Cost Unit: million S$

Items	PIE	KLE		PYE		
		Route I	Route II	Route I	Route II	Route III
Direct Construction Cost	76.7	251.3	220.3	508.4	325.5	370.7
Contingency (10%)	7.7	25.1	22.0	50.8	32.6	37.1
Total	84.4	276.4	242.3	559.2	358.1	407.8
Total/Length Thou.S$/m	10.2	80.5	71.3	56.5	36.1	42.1

Table 6 Land Acquisition & Compensation Cost

Items		KLE				PYE					
		Route I		Route II		Route I		Route II		Route III	
		Area	No	Area	No	Area	No	Area	No	Area	No
Area & Number	Private	21.7	42	15.4	43	12.9	5	12.4	3	12.2	2
	Lease	32.8	16	31.7	15	55.6	18	101.8	17	40.9	7
	Total	54.5	58	47.1	58	68.5	23	114.2	20	53.1	9
Cost S$m		33.1		28.8		7.9		17.2		7.3	
Cost/Length S$/m		9,650		8,470		800		1,730		750	

Note: Unit ; Area:thousand m², No:Number of lots
No private land required for PIE

Table 7 Maintenance Cost Ratios to Initial Construction Cost (per km·year)

	Maintenance	Repair	Disaster	Total
Above ground	0.3%	0.2%	0%	0.5%
Under ground	2.0%	1.0%	0%	3.0%

Table 8 Yearly Maintenance Cost

Route Name	PIE	KLE				PYE					
		Route I		Route II		Route I		Route II		Route III	
	S$m	km	S$m	km	S$m	km	S$m	km	S$m	km	S$m
Above ground	0.38	0.83	0.83	19.5	1.10	20.3	1.63	22.1	1.63	21.4	1.85
Under ground	0.0	2.53	2.53	0.0	0.0	2.1	5.46	0.0	0.0	0.0	0.0
Total	0.38	3.38	3.38	19.5	1.10	22.4	7.09	22.1	1.63	21.4	1.85
MC/CC %	0.5		1.3		0.5		1.4		0.5		0.5

Note: MC;Maintenance cost, CC:Construction cost
"km" indicates total length of roads including ramps

with the additional investment and maintenance costs for the projects. The quantifiable economic benefits were mainly derived from the savings of vehicle operating costs and those of passenger's time costs.

These traffic cost savings for vehicle users were estimated and compared between the with-project alternatives and without-project situation settings as follows:

Table 9 Base Year and Conditions for Economic Analysis

Expressways	Base Year	Base Conditions for With/ Without Project Situations
PIE	1995	Do Nothing (Present Condition)
KLE	1997	Work on PIE Completed
PYE	2010	Work on PIE & KLE Completed

Note : With-project should add alternative on the base conditions.

The daily traffic costs estimates were calculated by using the daily vehicle-kilometers by speed and vehicle hours computed from the simulation of traffic assignment.

On the other hand, the economic cost of the projects was estimated through eliminating transfer elements such as taxes and import duties from the financial costs.

10.2 Results

From the economic point of view, all of the projects were considered feasible.

As the improvement project for PIE had a small amount of benefits, it was not feasible with an economic internal rate of return (EIRR) of 6.0%. However, for the PIE, some unquantifiable aspects such as reduction of traffic accidents and improvement of accessibility should be evaluated. The PIE qualified as feasible in this regard.

As to the alternative projects for KLE, the Route-II (viaduct scheme) had a higher EIRR of 69.3% than the Route-I (tunnel scheme) of 60.0%. As to the three alternatives for the PYE, an EIRR of 76.6% for the Route-I, 79.5% for Route-II, 83.7% for Route-III were estimated. Taking the net present value (NPV) and cost benefit ratio (CBR) into consideration, the Route-II was the most favorable on the economic terms.

Table 10 Results of EIRR, NPV CBR(B/C)

Expressway	Alternative Case	NPV(1,000S$)	CBR(B/C)	EIRR(%)
PIE	FinalAlternative	-25,342	0.58	6.0
KLE	Route-I (Tunnel)	1,185,673	8.31	60.0
	Route-II(Viaduct	1,215,183	10.16	69.3
PYE	Route-I (AirBase	3,146,306	35.72	76.6
	Route-II(Green	3,691,487	58.96	79.5
	Route-III(DefuAv	3,687,701	55.66	83.7

Note : Discounted Rate was 12% for NPV and CBR.

11. FINAL EVALUATION AND RECOMMENDATIONS

Alternatives of target expressways, ie. the improvement of PIE and construction of KLE and PYE, were preliminarily designed and the necessary findings were obtained.

As to the PIE, there was only one alternative for the Phase-II Study, selected among other alternatives in the Phase-I Study. This alternative was studied and finalized. The final alternative, as presented in previous parts of this paper, was proved to be feasible in socio-economic, technical and economical aspects.

The evaluation at this stage therefore was focussed in the KLE and PYE of the following alternatives;

KLE	Route - I	Tunnel/viaduct Alternative
	Route - II	Viaduct only Alternative
PYE	Route - I	Air Base (Viaduct/tunnel) Alternative
	Route - II	Green Belt (Viaduct/at-grade) Alternative
	Route -III	Defu Avenue (Viaduct) Alternative

11.1 Evaluation of Alternatives

The aspects and items shown in Table 11 were selected for final evaluation. Evaluation result was summarized in Table 12.

Table 11 Aspects and Items for Final Evaluation

Aspects	Items for Evaluation
1.Effects by Project itself	Balance with budget and cost such as construction, land acquisition, compensation, etc.
2.Economic Effects by Construction	Savings of time and vehicle running costs, Return for national economy
3.Improvement on Local Traffic	Serviceability to interchanges by local traffic, Decrease of traffic accidents
4.Impact on Surrounding Area	Changes in local traffic, utilization of space by grade separation, etc

Table 12 Evaluation of Alternatives for KLE and PYE

Evaluation Items	KLE		PYE		
	Route-I	Route-II	Route-I	Route-II	Route-III
Construction & Maintenance	Unfavorable	Acceptable	Unfavorable	Acceptable	Unfavorable
Cost Benefit Balance	Acceptable	Acceptable	Unfavorable	Acceptable	Acceptable
Traffic Safety	Unfavorable	Acceptable	Unfavorable	Acceptable	Acceptable
Local Traffic Service	Acceptable	Acceptable	Unfavorable	Acceptable	Acceptable
Local Environmental Impact	Acceptable	Unfavorable	Unfavorable	Acceptable	Acceptable
Admissibility as Assets	Acceptable	Unfavorable	Acceptable	Acceptable	Unfavorable
Total Evaluation Mark	Acceptable	Acceptable	Unfavorable	Favorable	Acceptable

(1) Construction and Maintenance Aspects

As to the KLE, the Route-I Alternative was evaluated to be inferior owing to construction difficulty at tunnel section and to the PYE the Route-II Alternative was superior because of more at-grade section than the others.

(2) Cost Benefit Balance

The marks for the KLE alternatives were same although there was a tunnel section in the Route-I Alternative. As to the PYE, the difference in construction costs affected the economic evaluation.

(3) Traffic Safety Aspect

As to the KLE, the Route-I Alternative was inferior because its alignment at the portal of tunnel was combined by very tight 600m radius with 3% gradient. For the PYE, the tunnel with the same unfavorable alignment would pose the same problems.

(4) Local Traffic Serviceability

Positive and negative impact on traffic and availability of space above and beneath the expressways were evaluated. Route-I Alternative of the KLE was a slightly more favorable because of better land usage above tunnel.

Route-I Alternative of the PYE was inferior because of poorer accessibility.

(5) Environmental Impact

Viaduct in Route-II Alternative of the KLE received unfavorable marks because of noise nuisance and privacy intrusion near the PIE/KLE Interchange. Route-I Alternative of the PYE was inferior to the others because of noise nuisance in the section above Airport Road and concentration of air pollutant at the portal of tunnel.

(6) Admissibility as City Assets

Unification of urban system had progressed in Singapore. The city assets in urban area should follow common style so as to be admissible in far future, as inherits of this era.

Route-I Alternative with tunnel section had higher marks in the KLE and Route-II Alternative with at-grade section out-skirt of Air Base had higher marks in the PYE.

11.2 Selection of Final Alternative

(1) KLE

Route-I Alternative with tunnel would have a higher possibility of traffic accident occurring at the tunnel stretch because of unfavorable horizontal and vertical alignment as well as interchange traffic. Route-II Alternative with viaduct all the way through did not comply with the admissibility as city assets. Eventually, two alternatives were marked the same as shown in Table 12.

In order to evaluate more comprehensively, the weightage of the items were studied as described below.

a. Item to which advanced technology could ease the negative impact could be less emphasized.
b. Item to which managerial care by a certain policy making could make an improvement when the trouble came about could be less emphasized.
c. Item of which problematic phenomena continued for a certain duration could be balanced by its time laps. The shorter duration was less emphasized.
d. The relationship of Item to citizen was proportional to the emphasis.

The result is summarized in Table 13.

Table 13 Weight of Evaluation Item

Evaluation Item	Concerned people of interest	Techno -logy evolve	Manage -rial care	Time laps trouble	Relati- on with citizen	Mark Ord- er
Const.& maiten.	Government	B	D	D	D	6
Cost Benefit	Nation	B	D	B	D	5
Traffic Safety	User	C	C	B	A	3
Local Traffic	User	C	C	B	B	4
Environment	Residents	C	C	B	A	2
City Assets	Nation	B	B	B	A	1

Note : Evaluation was marked by A to D in which A is the best.

The admissibility of urban facility, as a city asset and future inherit, could not be made up for by any means of replacement, but in the context of the society it would be established. On the other hand, traffic safety would involve such a flexibility as to be cared for by the technological and political measures based on the concurrent advancement of the age.

Reevaluating the alternatives by those items to the first and second emphasis, tunnel alternative was superior to the viaduct plan. However, the deficiency at the third Item on traffic safety could not be allowed to remain later in Singapore. Tunnel alternative could be recommended on the condition that the following measures should be incorporated on the implementing stage of the project.

a. **Strengthening of tunnel lightings.**
Brighter lighting was known to reduce traffic accidents. Lighting installation arrangement should be carefully studied.

b. **Readjustment of accesses to interchange.**
Weaving at interchange was generally a serious cause of accidents. Reduction of access services should be studied in this regard.

c. **Reconsidering of the regulation speed on the KLE.**
Although the KLE and PYE had been designed for 80km/hour, the Study Team recommended to reduce the regulation speed to 60 km/h in view

of traffic safety.

(2) PYE

The alternatives for PYE had been evaluated and the Route-II Alternative was recommended judging from the remarkable difference among them as shown in Table 12.

11.3 Recommendations

Suitable alternatives were selected for each of KLE and PYE after confirming their feasibilities in aspects of technical, economics and socio-economy.

The conclusion was arrived at with difficulty due to many restrictions imposed particularly on land use.

The followings were the Study Team's recommendations for the PWD to review in future upon accepting some result of this Study.

(1) Rezoning of Land Use at the Crossings of KLE, PYE and PIE

Proposed interchanges had services to almost all the directions of three expressways. The roads and structures would be so complicated that some negative impact on the environ would be unavoidable. A change in land use from housings to others was recommended to reduce impact, at least to residents.

(2) Classified Use of Expressways

It was a common understanding to separate grade and role of expressways so that they could contribute more in terms of reduction in travel time and accidents. To keep a higher grade of an expressway, there would need several basics such as avoiding common bus stops and mixed usage with frontage roads, providing enough distance between interchanges, etc. Some of the expressway systems were recommended to be reviewed thoroughly in the light of such understanding prior to implementation.

12. IMPLEMENTATION SCHEDULE

The Public Works Department was planning the expressway development programme with the following schedule for the start and completion of construction. The implementation schedule for the selected expressways was recommended considering the scale of project, the relative scheduling to the other expressways and the budget for expressway construction.

PIE	PIE/Woodsville Road IC - PIE/CTE IC	Completion in 1994
	PIE/CTE IC West - PIE/BKE IC	Completion in 1995
KLE	KLE/ECP IC - KLE/PIE IC	Completion in 1997
PYE	PYE/PIE IC - PYE/TPE IC	Completion in 2010

12.1 Project Cost

The construction cost was estimated on a basis of unit price in

the year 1990. The result was as summarized in Table 14.

Table 14 Estimated Project Cost (Unit:Mil.S$)

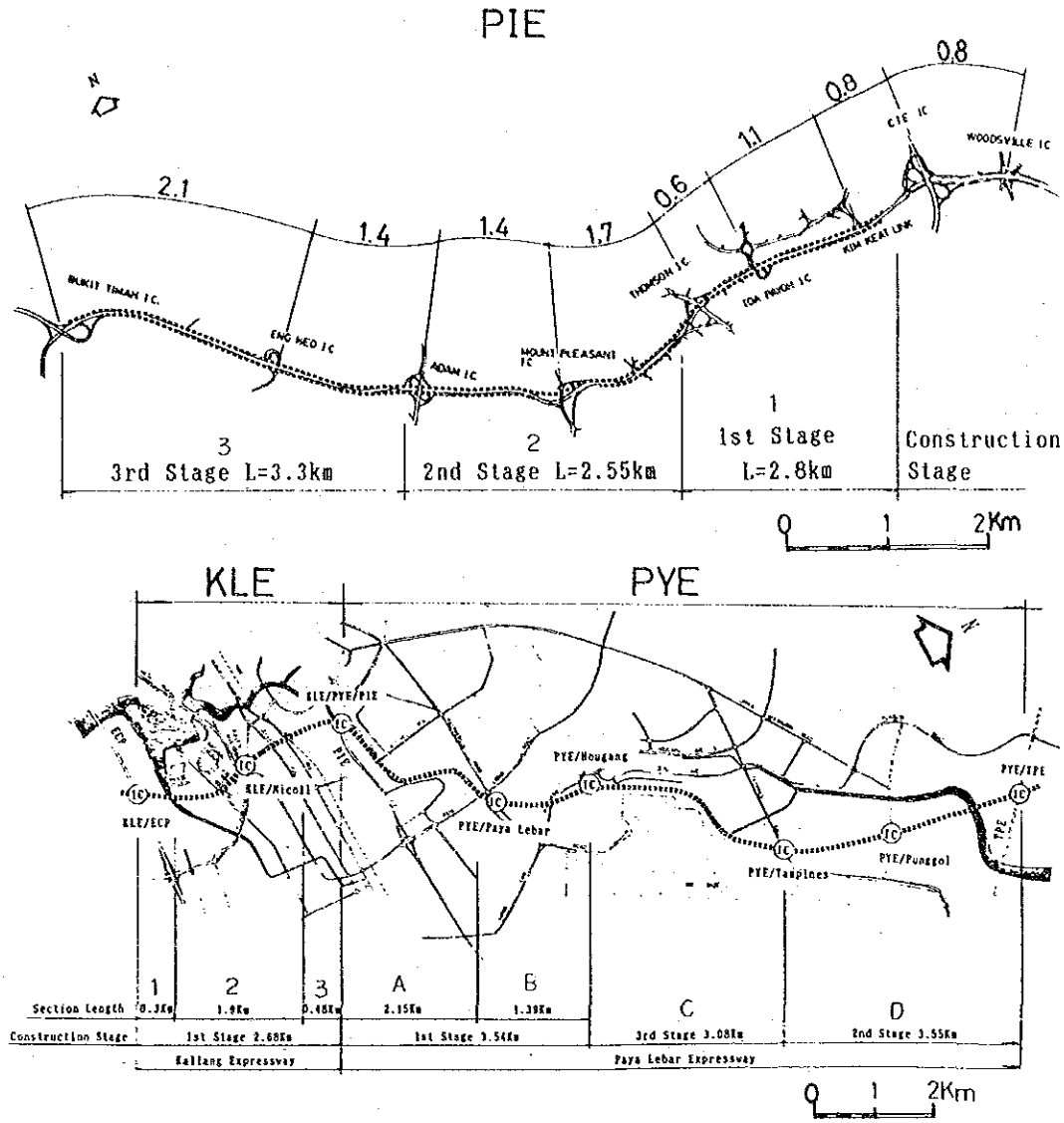
Items	PIE	KLE	PYE
Construction Cost	84.4	276.4	358.1
Land Acquisition and Compensation Costs	0.0	33.2	17.3
Contingencies (10%)	8.4	31.0	37.5
Total	92.8	340.6	412.9

12.2 Stage Construction

Expressway construction project required a huge amount of investment. In order to make effective use of it, stage construction was recommended. The stage construction was arranged as in Fig.17 taking into account the projected increase in traffic and regional development for each alternative.

12.3 Implementation Schedule

The implementation schedules for the selected expressways by stage construction was recommended as shown in Fig.17.



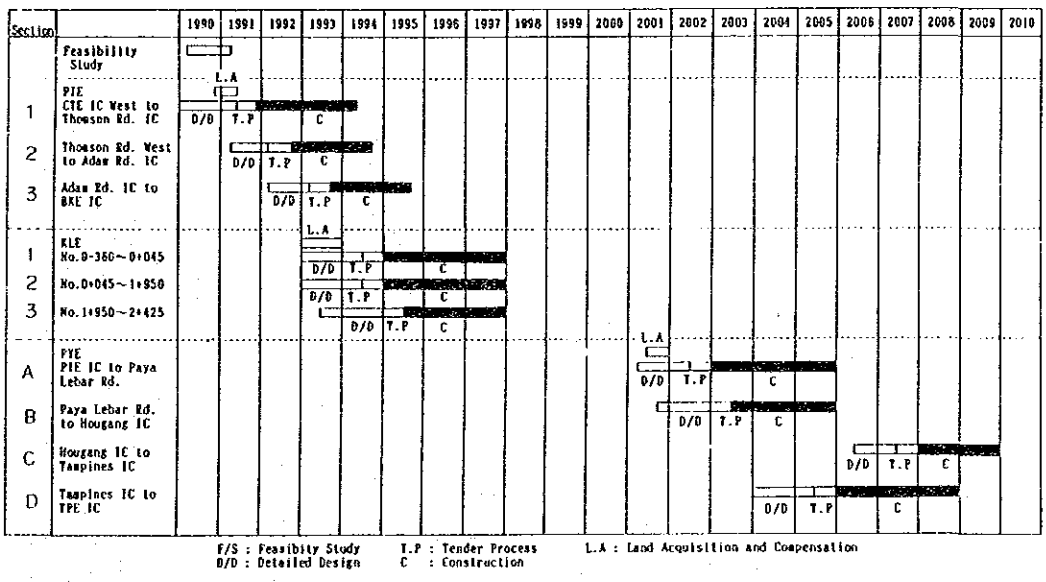
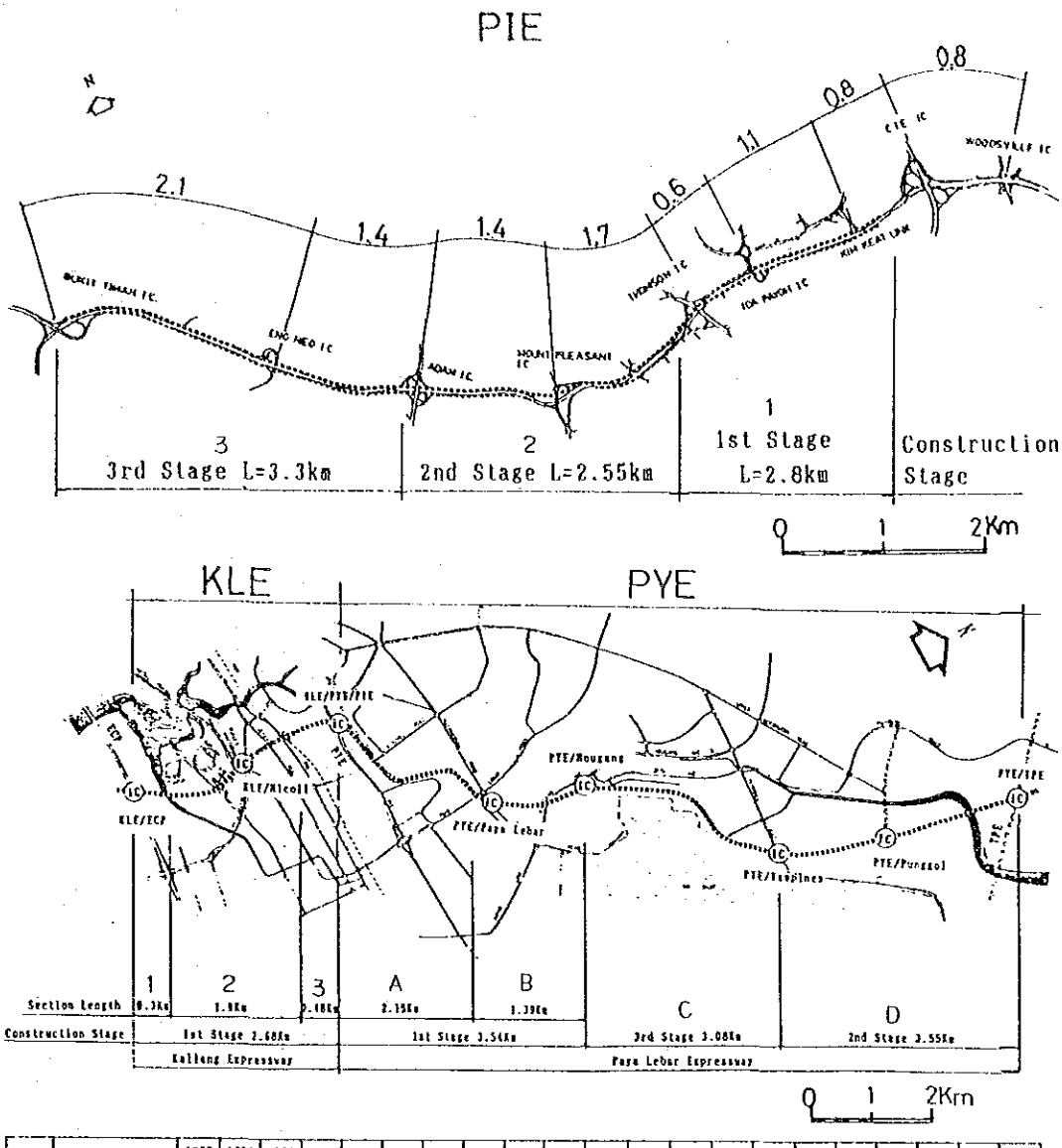


Fig. 17 Construction Scheduling for PIE & KLE & PYE



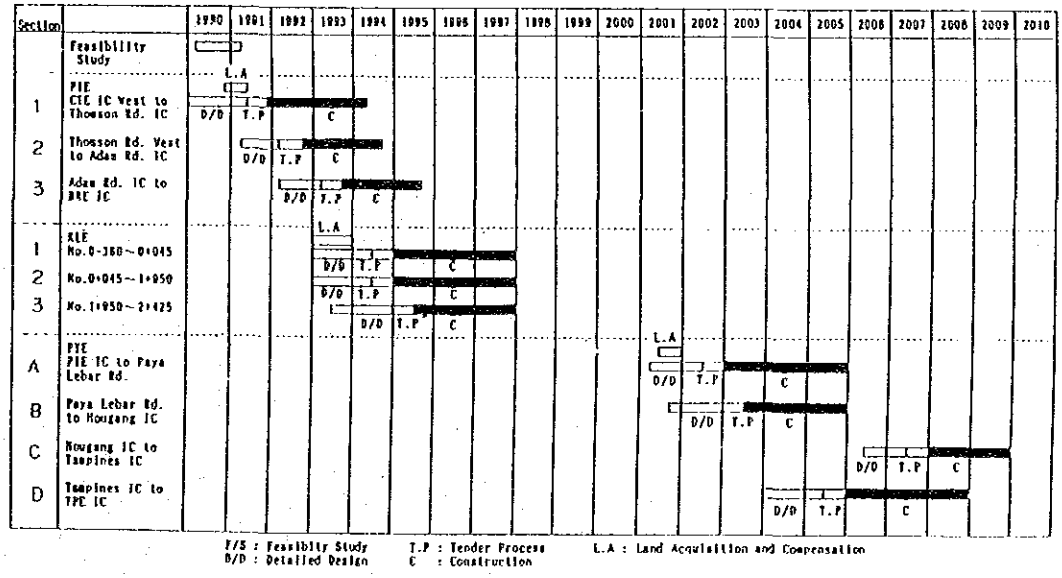


図17　PIE, KLE, PYEの実施計画

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