### 8.3.1 PIE

**1) Economic aspects**

The total of the construction cost, land acquisition cost and maintenance cost for Phase I is calculated as there is a need to compare/assess the economic aspect of each alternative plan based on the knowledge of estimated total construction cost in order to select alternatives for Phase II. The calculation at Phase I stage is a rough estimation based on information derived from a map of scale 1:5000. However, the calculation for PIE is done with maximum accuracy.

Unit price was decided after a rough calculation followed by discussions with PWD. Calculation is based on the following assumptions ;

- Unit price was calculated based on the prevailing economic conditions of July, 1990.
- Construction cost is financed in local currency.
- Contingency allowance is made up of 10% of the total construction, land acquisition, and compensation cost.
- Contract Preliminary and Mobilization costs are made up of 10% of the total construction cost.
- Maintenance cost for at-grade and flyover structure is established based on the recorded expenditure of year 1989/1990.

As the above assumptions are common for PIE, KLE and PYE, the description in the chapters for KLE and PYE is abbreviated.

The construction cost for PIE is shown in Table 8.3. From the Table, it is derived that the cost for the flyover proposals in II-1 and II-2 are relatively high as compared to ground proposal in I. Quantitatively comparing, proposal II-1 are 3 and 5.4 times more costly than proposal I respectively. Although it can be said that there is little difference between the different proposals under proposal I, it was realized that the cost for the construction of interchange structure carries a very high weightage of 50% of the total cost even for proposal I.

The unit price per metre for each proposal is shown below. This unit price consists of construction cost, which includes construction of interchange but not land acquisition, Preliminary/Mobilization and Contingency cost.

| | | |
|---|---|---|
| I-1-a | Widening of existing road | S$ 49 Mil.(S$ 5400/m) |
| I-1-b | Widening of existing road | S$ 49 Mil.(S$ 5400/m) |
| I-1-c | Widening of existing road | S$ 51 Mil.(S$ 5500/m) |
| I-1-d | Widening of existing road | S$ 51 Mil.(S$ 5500/m) |
| II-1 | Widening of existing road + flyover | S$145 Mil.(S$ 15900/m) |
| II-2 | Flyover for the whole line | S$271 Mil.(S$ 29600/m) |

**2) Construction aspects**

There has never been an authorized method to quantify the difficulty of construction work. In other words, difficult construction will result in an increase of the Construction cost and period, i.e. construction

## Table 8.3 Construction cost and maintenance cost ( PIE )

PIE(1)

Unit: Million S$

| | ITEMS | | UNIT | UNIT PRICE S$ | I-1-a Quantities | I-1-a Amount | I-1-b Quantities | I-1-b Amount | I-1-c Quantities | I-1-c Amount | I-1-d Quantities | I-1-d Amount |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CONSTRUCTION | EARTH WORK | | M^3 | 4 | 160,950 | 0.64 | 166,760 | 0.67 | 167,390 | 0.67 | 167,390 | 0.67 |
| | PAVEMENT | | M^2 | 40 | 193,060 | 7.72 | 196,940 | 7.88 | 221,850 | 8.87 | 221,850 | 8.87 |
| | ROADSIDE DRAIN | | M | 215 | 15,570 | 3.35 | 15,570 | 3.35 | 15,570 | 3.35 | 15,570 | 3.35 |
| | LANE MARKING AND TRAFFIC SIGNS | | M | 48 | 8,780 | 0.42 | 8,750 | 0.42 | 8,750 | 0.42 | 8,750 | 0.42 |
| | IMPACT GUARD RAILING | | M | 65 | 20,070 | 1.30 | 19,690 | 1.28 | 19,690 | 1.28 | 19,690 | 1.28 |
| | TREE PLANTING | | M | 120 | 8,780 | 1.05 | 8,750 | 1.05 | 8,750 | 1.05 | 8,750 | 1.05 |
| | CENTER DIVIDER | | M | 100 | 5,700 | 0.57 | 5,700 | 0.57 | 5,700 | 0.57 | 5,700 | 0.57 |
| | STREET LIGHTING | | M | 173 | 8,330 | 1.44 | 8,330 | 1.44 | 8,330 | 1.44 | 8,330 | 1.44 |
| | FLYOVER STRUCTURE | | M^2 | 1,200 | 15,680 | 18.82 | 15,680 | 18.82 | 15,680 | 18.82 | 15,680 | 18.82 |
| | CULVERT | | M^2 | 2,600 | 990 | 2.57 | 990 | 2.57 | 990 | 2.57 | 990 | 2.57 |
| | DEMOLITION | CONCRETE | M^3 | 700 | 4,990 | 3.49 | 4,990 | 3.49 | 4,990 | 3.49 | 4,990 | 3.49 |
| | | PAVEMENT | M^2 | 9 | 32,110 | 0.29 | 30,180 | 0.27 | 54,460 | 0.49 | 54,460 | 0.49 |
| | REMOVAL | PEDE. BRD | EACH | 270,000 | 3 | 0.81 | 3 | 0.81 | 3 | 0.81 | 3 | 0.81 |
| | OTHERS | | | | | 2.12 | | 2.13 | | 2.19 | | 2.19 |
| | SUB TOTAL | | | | | 44.61 | | 44.75 | | 46.03 | | 46.03 |
| | PRE. CHARGE/MOBI.(10%) | | | | | 4.46 | | 4.47 | | 4.60 | | 4.60 |
| LAND ACQUISITION | PL | | M^2 | | 3,910 | | 3,910 | | 3,910 | | 3,910 | |
| AND COMPENSATION | SL | | M^2 | | 157,040 | | 162,850 | | 163,480 | | 163,480 | |
| SUB TOTAL | | | | | | 49.07 | | 49.22 | | 50.63 | | 50.63 |
| CONTINGENCY (10%) | | | | | | 4.91 | | 4.92 | | 5.06 | | 5.06 |
| TOTAL | | | | | | 53.98 | | 54.15 | | 55.69 | | 55.69 |
| MAINTENANCE COST | ABOVE GROUND | | | | | 10.2 | | 10.2 | | 10.2 | | 10.2 |
| (Annual Cost) *10^3 S$/Km | TUNNEL | | | | | - | | - | | - | | - |

PIE(2)

Unit: Million S$

| | ITEMS | | UNIT | UNIT PRICE S$ | II-1 Quantities | II-1 Amount | II-2 Quantities | II-2 Amount |
|---|---|---|---|---|---|---|---|---|
| CONSTRUCTION | EARTH WORK | | M^3 | 4 | 127,660 | 0.51 | 44,500 | 0.18 |
| | PAVEMENT | | M^2 | 40 | 148,730 | 5.95 | 64,900 | 2.60 |
| | ROADSIDE DRAIN | | M | 215 | 11,210 | 2.41 | 1,800 | 0.39 |
| | LANE MARKING AND TRAFFIC SIGNS | | M | 48 | 8,330 | 0.40 | 8,330 | 0.40 |
| | IMPACT GUARD RAILING | | M | 65 | 15,280 | 0.99 | 4,400 | 0.29 |
| | TREE PLANTING | | M | 120 | 8,330 | 1.00 | 8,330 | 1.00 |
| | CENTER DIVIDER | | M | 100 | 5,200 | 0.52 | 3,200 | 0.32 |
| | STREET LIGHTING | | M | 173 | 8,330 | 1.44 | 8,330 | 1.44 |
| | FLYOVER STRUCTURE | | M^2 | 1,200 | 91,480 | 109.78 | 190,010 | 228.01 |
| | CULVERT | | M^2 | 2,600 | 990 | 2.57 | 0 | 0.00 |
| | DEMOLITION | CONCRETE | M^3 | 700 | 54 | 0.04 | 0 | 0.00 |
| | | PAVEMENT | M^2 | 9 | 21,070 | 0.19 | 20,400 | 0.18 |
| | REMOVAL | PEDE. BRD | EACH | 270,000 | 0 | 0.00 | 0 | 0.00 |
| | OTHERS | | | | | 6.29 | | 11.74 |
| | SUB TOTAL | | | | | 132.09 | | 246.54 |
| | PRE. CHARGE/MOBI.(10%) | | | | | 13.21 | | 24.65 |
| LAND ACQUISITION | PL | | M^2 | | 3,910 | | 3,910 | |
| AND COMPENSATION | SL | | M^2 | | 127,420 | | 172,460 | |
| SUB TOTAL | | | | | | 145.30 | | 271.20 |
| CONTINGENCY (10%) | | | | | | 14.53 | | 27.12 |
| TOTAL | | | | | | 159.83 | | 298.32 |
| MAINTENANCE COST | ABOVE GROUND | | | | | 10.2 | | 10.2 |
| (Annual Cost) *10^3 S$/Km | TUNNEL | | | | | - | | - |

difficulty quantitatively reflects to the cost and period. However, the more special and difficult the construction method being applied, the more uncertain factors are accompanied with the construction activity, such as unexpected expenditure, delay of working schedule and danger of accidents. Even if conventional labour works were executed, particular skill in site management is required in such places as where construction activity is performed by detouring or diverging busy traffic. Uncertain factors as described above cannot be covered by the cost and period estimation, furthermore the construction works involving uncertainty itself might affect the warranty of the Alternative Formulation.

Construction difficulty is listed in Table 8.4 on the basis of common experience.

**Table 8.4 Classification of construction difficulty**

| | Construction working procedure | Factor of Difficulty |
|---|---|---|
| Require special technique and management | 1.Demolition of over-bridge above expressway<br>2.Foundation work close to MRT in shielded tunnel<br>3.Soil stabilization ( chemical grouting )<br>4.Long span S-curve girder | 1.2 |
| Technically difficult | 1.Demolition of rampway structure and pedestrian bridge<br>2.Widening of at-grade highway<br>3.Girder erection over highway<br>4.Foundation work close to existing structure<br>5.Median shifting<br>6.Switching of rampway traffic<br>7.Building pier in canal | 1.1 |
| Conventional | 1.Construction of rampway viaduct<br>2.Access road preparation<br>3.Clearing and leveling site<br>4.Sheeting and structural excavation<br>5.Pier building & backfilling<br>6.Foundation work<br>7.Girder erection by crane<br>8.PC girder casting by bent<br>9.Bridge surfacing & railing<br>10.Protection for under traffic | 1.0 |

On the construction aspects, the widening works covering interchanges and roadways all through the PIE route is comprehensively evaluated.

Evaluation is represented by a score of 5 marks based on the examination on construction procedure as included in Appendix 8.1 and is integrated to the total score in accordance with the items of the Evaluation

Criteria.

The score from the result of the same grade widening alternative and the viaduct alternative is as listed below according to the summation of factors of difficulty for working items. (except for conventional working items.)

| | Score |
|---|---|
| Alternative I (same grade widening) | 2 |
| Alternative IV (viaduct construction) | 3 |

The Alternative I of the same grade widening has been evaluated to the score 2, indicating "fairly complicated" for the following reasons comparing to the Alternative IV,

- Reconstruction work of Toa Payoh overbridge.
- Demolition works of loop shaped rampway viaduct at Thomson Interchange (Pier column penetrating canal box culvert)
- Demolition works of 3 pedestrian bridges

Construction period for the Alternatives is estimated and evaluated as shown in Table 8.5.

**Table 8.5 Construction period and evaluation score**

| Alternative | Characteristics | Period (Day) | Period (Month) | Ratio to Average | Score |
|---|---|---|---|---|---|
| I-1-a | Same grade widening | 2,137 | 71 | 0.29 | 5 |
| I-1-b | PWD plan with collector | 2,113 | 70 | 0.28 | 5 |
| I-1-c | Rampway Integration | 2,201 | 73 | 0.30 | 5 |
| I-1-d | Kim Keat Ramp with Viaduct | 2,201 | 73 | 0.30 | 5 |
| II-1 | Viaduct over the Stretch | 6,947 | 232 | 0.94 | 2 |
| II-2 | Viaduct over all through the Route | 13,007 | 434 | 1.76 | 1 |

**3) Traffic aspects**

The assessment/analysis result of the proposals for PIE from traffic technique's viewpoint are as follow :

(1) The Assessment during Construction Period

The assessment items for traffic technique during construction period are as follows:

a. No of existing lanes to be maintained during construction period (capacity).
b. Possibility to close down the existing ramps (accessibility).

There is a need to limit the existing 3 lanes (one way) road to at least 2 lanes while construction is in progress for the proposal to widen existing road (alternative I). On the other hand, the construction of flyover (alternative II) can be done without affecting the traffic flow on existing road and thus maintaining the no. of lanes on existing road.

As for the case of closing down the ramps on existing road during construction period, there is a need to close down the ramps mainly at night to carry out construction work in order to widen the road. Whilst there is no requirement for this if a flyover is to be built. The result of the assessment on traffic technique during construction period is summarized in Table 8.6:

**Table 8.6 Scores on traffic technique during construction period**

| | Alternative I | Alternative II |
|---|---|---|
| Capacity | 3 | 4 |
| Accessibility | 3 | 4 |

(2) Assessment during Operational Period

Traffic smoothness and traffic safety are the assessment items for traffic technique after the road is in use.

In the Alternative I, the problem in traffic engineering is the stretch between Thomson IC and CTE/PIE IC where on-ramp and off-ramp repeat at short intervals. In the stretch, 4 alternatives with different traffic operation are proposed as shown in Fig. 8.2 and their characteristics and problems on traffic operation are summarized in Table 8.7. As shown in the table, I-1-a in the eastward bound way and I-1-d in the westward bound way have no particular problem in view of traffic capacity and safety. In the case of traffic safety preference, I-1-b is excellent. Therefore a staged operation is recommended as to commencing with operation of I-1-b until the year 2000 while observing the traffic increase and then to operate by I-1-a and I-1-d. (see Appendix 8.2)

In the Alternative II, the problem in traffic engineering is the requirement of the through-traffic user to utilize viaduct in the viaduct stretch. A expected through-traffic volume to use viaduct in the viaduct stretch is abstracted into Table 8.8. As shown in the table, in the Alternative II-2 at the viaduct fly over from Eng Neo IC to CTE/PIE IC, through-traffic volume in round trip using the viaduct accounts for the amount up to which needs one lane with conclusion that viaduct is not necessary. In the Alternative II-1 to fly over from Mount Pleasant IC to CTE/PIE IC, through-traffic volume in round trip to use viaduct accounts for the amount up to which needs 3 lanes with conclusion that it is significant to separate access flow in low speed and through flow in high speed. Regarding the viaduct alternative, traffic safety aspect requires attention to weaving traffic where access traffic and through

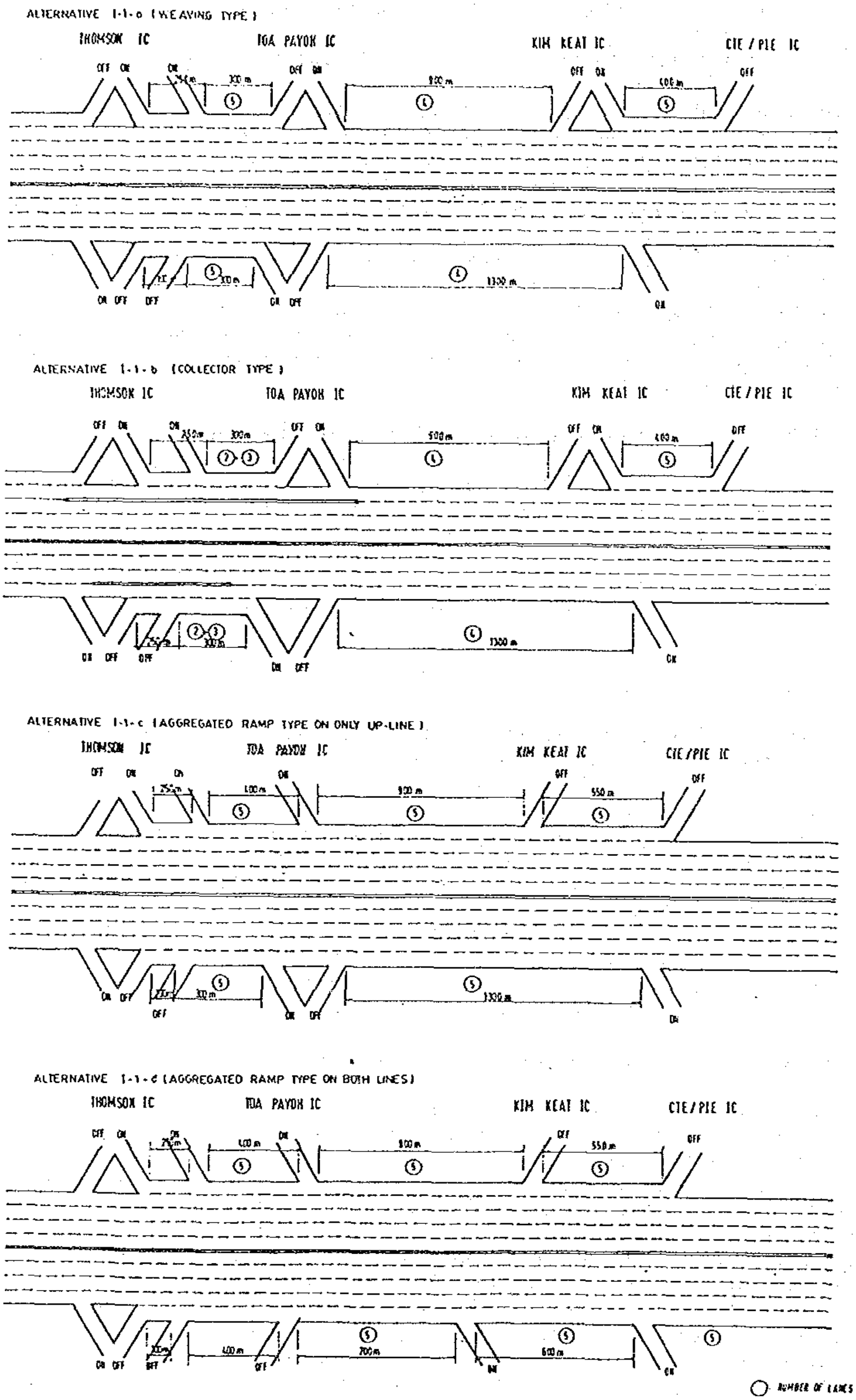


Fig. 8.2 Alternative on the PIE section from Thomson IC to PIE/CTE IC (At-grade widening)

traffic to use interchanges meet weaving phenomena on the main carriageway at the merging section of viaduct ending.

**Table 8.7 Assessment of proposals (PIE/Thomson IC - PIE/CTE IC)**

| | I-1-a | I-1-b | I-1-c | I-1-d |
|---|---|---|---|---|
| CONTENT | Implemented with weaving method for interval between Thomson and Toa Payoh. | Separate passing traffic from ON-OFF traffic at the interval between Thomson and Toa Payoh with the use of converging / diverging road. | Based on proposal I-1-a and for PIE eastbound, centralise OFF ramp at Kim Keat (remove off ramp at Toa Payoh) and ON ramp at Toa Payoh (remove on ramp at Kim Keat) to reduce the number of ON, OFF ramp. | Based on proposal I-1-c and for PIE westbound shifting of the ON ramp at Toa Payoh to Kim Keat. |
| SMOOTHNESS | According to the result of a simulation done on traffic flow, the speed of eastbound traffic is about 45 km/h and about 55km/h for westbound traffic at the weaving interval between Thomson and Toa Payoh.(Appendix 9.2) | If the interval between Thomson and Toa Payoh is operated with converging/ diverging rd., this portion will be overloaded and traffic management will not be possible. (Appendix 9.2) | The Toa Payoh IC (in Changi direction) is overloaded with incoming traffic. Traffic managment become impossible. (Appendix 9.2) | The westbound traffic at the merging portion which was shifted to Kim Keat vicinity is about 60km/h. No problem with traffic management. (Appendix 9.2) |
| SAFETY | Due to the existence of weaving traffic, the degree of conflict between vehicles are high. | As fast and slow traffic are physically separated, it is very safe. | Although it is safer without the weaving traffic, the concentration of the merging traffic and separated traffic at one location reduces the safety at these portions. | No problem with safety. |

**Table 8.8 Accessible volume with viaduct**

unit : pcu/hour

| Alternative | Accessible Volume with Viaduct | | |
|---|---|---|---|
| | Morning Peak | Off Peak | Evening Peak |
| II - 1 | 4,244 (2) | 5,442 (3) | 5,809 (3) |
| II - 2 | 1,338 (1) | 858 (1) | 578 (1) |

note : figure with ( ) shows the necessary number of lanes

Accordingly based on the above study, evaluation from traffic engineering aspect for the case under operation is given in Table 8.9.

**Table 8.9 Evaluated score in traffic engineering aspect under service**

| | Alternative I | | | | Alternative II | |
|---|---|---|---|---|---|---|
| | 1 - a | 1 - b | 1 - c | 1 - d | 1 | 2 |
| Capacity | 3 | 2 | 3 | 4 | 4 | 2 |
| Safety | 3 | 4 | 3 | 4 | 3 | 3 |

## 4) Others

Other items are the noise and vibration during construction, the noise and vibration after usage has started, scenery, area separation, possibility of future road expansion and the efficiency of land usage. (Appendix 8.3)
Most of these items have to be assessed based on quantitative judgment. The result of the assessment for each proposal is shown in Table 8.10.

**Table 8.10 Analysis on various feature ( PIE )**

(PIE)

| ITEMS / ALTERNATIVE | | | I-1-a At-grade | I-1-b At-grade | I-1-c At-grade | I-1-d At-grade | II-1 Viaduct | II-2 Viaduct |
|---|---|---|---|---|---|---|---|---|
| Noise & Vibration under Construction Work | | | Breaking of existing structure and driving of piles for foundation of structure produce severe noise and vibration to the residential area. However, except at adjacent areas of interchanges, will be low and temporary only. | | | | The adjacent area along the PIE will experience severe noise and vibration pollution during the whole construction period. | |
| AFTER CONSTRUCTION | Environmental Impact | Noise & Vibration | Noise pressure level will be increased a few dB(A) in accodance with the widening of existing expressway. Particularly, in high-rise areas along the expressway. However, this alternative will not drastically change the existing noise level. | | | | Construction of viaduct will increase the noise pressure level at the higher floors than on the road surface of viaduct. There are several high- and medium-rise buildings along the expressway, therefore noise level will definitely increase. | |
| | | Aesthetic | The widening from 6 lanes to 8 will hardly change the aesthetic at eye level, except from the upper floors of tall buildings. | | | | The existence of mass-volume structure above ground level will give a sense of oppression to the residents living along the expressway. | |
| | | Community Separation | There will be no change in the existing social activities. | | Removal of existing ramps will cause inconvenience to most ramp users. | | Construction of grade-separated viaduct will not bring any additional problems to the unity of the existing community. | |
| | Possibility for Future Extension | | This alternative has the possibility of future extension by adopting the grade-separated structure or by the construction of additional lanes on the opposite sides. | | | | Construction of viaducts on the both sides of existing expressway restrict the future extension of lanes. | |
| | Effectiveness on the Land Usage | | Widening of existing expressway will require a wide land acquisition, and a wide road area of 8 lanes will be an obstruction to the effective utilization of land. | | | | Viaduct construction requires narrower land as compared to at-grade widening. Besides, the space under the viaduct can be utilized effectively. | |

## 8.3.2 KLE

### 1) Economic aspects

Construction cost of KLE accounts for the result as shown in Table 8.11.

**Table 8.11 Construction cost and maintenance cost**

Unit : Million S$

| | ITEMS | | UNIT | UNIT PRICE S$ | I-1-C | | II-2-C | | III-1-A | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Quantities | Amount | Quantities | Amount | Quantities | Amount |
| CONSTRUCTION | EARTH WORK | | M^3 | 4 | 12,700 | 0.05 | 3,200 | 0.01 | 6,800 | 0.03 |
| | PAVEMENT | | M^2 | 40 | 8,260 | 0.33 | 2,070 | 0.08 | 4,430 | 0.18 |
| | ROADSIDE DRAIN | | M | 215 | 560 | 0.12 | 140 | 0.03 | 300 | 0.06 |
| | LANE MARKING,AND TRAFFIC SIGNS | | M | 48 | 3,450 | 0.17 | 3,180 | 0.15 | 3,295 | 0.16 |
| | IMPACT GUARD RAILING | | M | 65 | 1,120 | 0.07 | 280 | 0.02 | 600 | 0.04 |
| | TREE PLANTING | | M | 120 | 3,450 | 0.41 | 3,180 | 0.38 | 3,295 | 0.40 |
| | CENTER DIVIDER | | M | 100 | 280 | 0.03 | 70 | 0.01 | 150 | 0.02 |
| | STREET LIGHTING | | M | 173 | 3,450 | 0.60 | 3,180 | 0.55 | 3,295 | 0.57 |
| | FLYOVER STRUCTURE | | M^2 | 1,200 | 105,000 | 126.00 | 48,110 | 57.73 | 168,380 | 202.06 |
| | DEPRESSED STRUCTURE | COVERD | M^2 | 2,600 | 36,990 | 96.17 | 103,660 | 269.52 | 0 | 0.00 |
| | | COVERD UNDER CANAL | M^2 | 3,380 | 0 | 0.00 | 3,350 | 11.32 | 0 | 0.00 |
| | | SEMI-COVERD | M^2 | 1,660 | 35,530 | 58.98 | 23,460 | 38.94 | 0 | 0.00 |
| | PEDESTRIAN BRIDGE | | EACH | 250,000 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | DEMOLITION | CONCRETE | M^3 | 100 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | | PAVEMENT | M^3 | 30 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | REMOVAL | PEDESTRIAN BRIDGE | EACH | 20,000 | 3 | 0.06 | 3 | 0.06 | 3 | 0.06 |
| | OTHERS | | | | | 14.15 | | 18.94 | | 10.18 |
| | SUB TOTAL | | | | | 297.14 | | 397.75 | | 213.74 |
| | PRE. CHARGE / MOBI.(10%) | | | | | 29.71 | | 39.78 | | 21.37 |
| LAND ACQUISITION AND COMPENSATION | | PL | M^2 | | 13,950 | | 13,950 | | 13,350 | |
| | | SL | M^2 | | 614,820 | | 603,920 | | 603,930 | |
| SUB TOTAL | | | | | | 326.86 | | 437.53 | | 235.11 |
| CONTINGENCY (10%) | | | | | | 32.69 | | 43.75 | | 23.51 |
| TOTAL | | | | | | 359.54 | | 481.28 | | 258.63 |
| MAINTENANCE COST | | ABOVE GROUND | | | | 10.2 | | 10.2 | | 10.2 |
| (Annual Cost) *10^3 S$/Km | | TUNNEL | | | | 100.0 | | 100.0 | | 100.0 |

As clarified in the table, the alternative with a tunnel from ECP to MRT is expensive, 1.3 times to 1.9 times more than the other alternatives, whereas Alternative III-1-a with viaduct all through the route is the most economical. This is because construction cost of the tunnel is more than twice the viaduct. In the view point of cost, tunnel alternative is disadvantageous. In addition, KLE requires great scale of interchanges at the crossings to ECP, Nicoll Highway and PIE. Beside, structures occupy all the stretch of the route with a result of rather high cost per length. Construction cost per length is shown below where interchanges are included but not land acquisition, Preliminary/Mobilization and Contingency cost.

| | | |
|---|---|---|
| I-1-c | Viaduct + Tunnel | S$ 327 Mil.(S$ 86100/m) |
| II-2-c | Tunnel | S$ 438 Mil.(S$ 125100/m) |
| III-1-a | Viaduct | S$ 235 Mil.(S$ 64900/m) |

## 2) Construction aspects

### Alternative I

Tunneling type and viaduct type are applied in this Alternative. Semi-covered tunnel is the longest among the Alternatives. At the crossing point over Geylang River, profile slopes to the steep gradient of 4% resulting in the limitation on the girder depth of the crossing bridge. Following the limitation, slenderizing of girder depth has been achieved by locating the bridge pier inside the waterway of Geylang River. This selection brings on somewhat difficult construction, but not yet crucial because of the moderate amount of flood discharge on Geylang River.

Construction of semi-covered tunnel requires traffic detouring at the crossing to Nicoll Highway. In the same way, open cut works will obstruct the current traffic in city area from Mountbatten Road to Sims Avenue to the south of MRT viaduct.

Underpassing the MRT viaduct requires close construction with careful management. Appreciation of the construction difficulty yields the score of 2, i.e. fairly complicated ( refer to Appendix 8.4(1)).

### Alternative II

Below the East Coast Parkway, underground interchange, presumably on a huge scale is being proposed. Consequently the tunnel structure stretches some 2km distance from under Geylang River to Sims Avenue with portal approach in trough structure. Open cut works in city area on the longer stretch than the Alternative I obstructs against the current traffic. Tunnel length of 2km requires ventilation and drainage facility resulting in the acquisition of facility location , expenditure of installation and operating cost, and maintenance costs expected constantly in future.

Underpassing the MRT viaduct requires close construction as in the Alternative I. There is no problem in the connection with the PYE in viaduct structure. This Alternative has a particular point that underpassing tunneling below Geylang River enjoins the waterway detouring. Appreciating of the construction difficulty yields the score of 2, i.e. fairly complicated (refer to Appendix 8.4(2)).

### Alternative III

This Alternative proposes viaduct structure to convey all through the route. Profile elevation is determined from the vertical clearance over ECP and MRT viaduct with result in the structural height of 13m above the ground level. This elevation seems somewhat higher than the easy erection of girder beams. The southern area to Nicoll Highway has abundant space for construction use and for variable design option, whereas the Kallang Park area having a broad view is suitable to long span bridge, accordingly on the widely parted column line correspondent to the river.

To the contrary of the Alternative I, more flat profile allows the balancing span allocation at the crossing bridge of Geylang River without pier location inside waterway.

Erection works of precast beam girder in city area to the north of

Mountbatten Road is likely to obstruct the current traffic and community life to a certain degree.

Erection works across MRT viaduct should utilise the launching method in order to prevent any objects falling on the MRT line. Launching method enjoins high cost and special technique. Not only over MRT line but also over many streets open to public the protection cover should be furnished against falling accidents. However, this is not a particularly complicated construction method in general. Appreciation of the construction difficulty yields the score of 3, i.e. meaning standard (refer to Appendix 8.4(3)).

Construction period for the Alternatives is estimated and evaluated as shown in Table 8.12.

**Table 8.12 Construction period and evaluation score**

| Alternative | Characteristics | Period (Day) | Period (Month) | Ratio to Average | Score |
|---|---|---|---|---|---|
| I | Viaduct + Tunnel | 10,735 | 358 | 1.12 | 2 |
| II | All through Tunnel | 11,800 | 393 | 1.23 | 1 |
| III | All through Viaduct | 6,219 | 207 | 0.65 | 5 |

**3) Traffic aspects**

The results of assessment and analysis on all the alternative plans for KLE in relation to traffic smoothness and safety are as follows :

(1) Smoothness ( Capacity )

In general, highway capacity varies with such conditions as cross section composition, horizontal alignment, vertical alignment and presence of tunnel. For example, traffic capacity decreases in the highway section with a curve of small radius, with steep gradient and with tunnel covering. Therefore, the alternatives for KLE are evaluated relatively, from the view points of traffic smoothness, to assure traffic capacity by using an evaluation index as defined in Formula I. Factors that affect traffic capacity are assigned curve radius, longitudinal gradient and tunnel presence, except for cross section components, because the existing lanes are secured with enough width to avoid a reduction in traffic capacity.

$$INDEX_C = \frac{(Rci+Ici+Tci)}{N} \quad \text{...... Formula-(I)}$$

where : $INDEX_C$ : Index for Capacity
Rci : Curvature Effect
Ici : Gradient Effect
Tci : Tunnel Effect
N : Highway section

Formula I includes Rci, Ici and Tci as specified in Table 8.13. At present the correlations between traffic capacity and curve radius, longitudinal gradient and tunnel presence have not yet been quantified, therefore the effect of curve radius is represented by adaptation of the minimum of 400m, respectively the effect of longitudinal gradient by adaptation of 4% and the effect of tunnel by presence of tunnel section.

**Table 8.13 Presence code of effect**

| | | |
|---|---|---|
| Rci (Curve radius) | R > 400m | 0 |
| | R < 400m | 1 |
| Ici (Longitudinal gradient) | I < +4% | 0 |
| | I > +4% | 1 |
| Tci (Tunnel) | Without | 0 |
| | With | 1 |

The set Rci, Ici and Tci by each different highway section are included in Appendix 8.4(1). Table 8.14 indicates the safety evaluation score (INDEXc) for each Alternative.

**Table 8.14 Capacity evaluation score**

| | I - 1 - c | II - 2 - c | III - 1 - a |
|---|---|---|---|
| INDEX | 1.00 | 0.83 | 0.25 |

The view point of smoothness recommends III-1-a as the best followed by II-2-c and I-1-c.

(2) Safety

Traffic safety is to be evaluated from the risk of accident occurrence in the alternatives by using an evaluation index as defined by Formula II below. Factors which effect accident risk are to cover curve radius, longitudinal gradient and tunnel presence.

$$INDEX_S = \frac{E\ (RsixIsixTsi)}{N} \quad \text{....... Formula-(II)}$$

where : $INDEX_S$ : Evaluation Index
Rsi : Factor to adjust for horizontal curve
Isi : Factor to adjust for gradient
Tsi : With of Without Tunnel
with Tunnel = 1.4 without Tunnel = 1.0

The determination of Rsi, Isi is based on the results of the accident analysis of the express highway in Japan and is set as shown in Fig. 8.3 and 8.4.

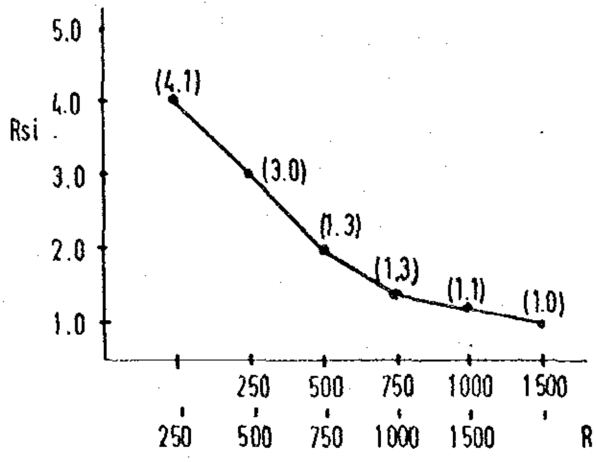


Fig. 8.3 Set value of Rsi

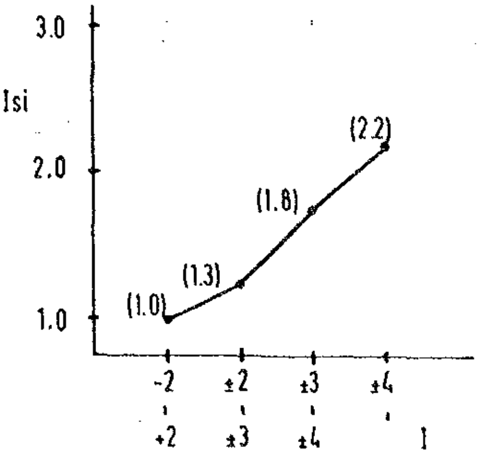


Fig. 8.4 Set value of Isi

The set values of Rsi, Isi and Tsi in the respective regions where horizontal alignment changes, are included in Appendix 8.4(2). The evaluated safety index obtained for each comparative study is shown in Table 8.15.

**Table 8.15 Evaluated safety index**

| | I-1-c | II-2-c | III-1-a |
|---|---|---|---|
| Index | 3.87 | 3.41 | 1.88 |

From the viewpoint of safety, III-1-a is the best, followed by II-2-c and I-1-c.

Based on the above study results, the grading and evaluation of traffic technicalities after operation was done as shown in Table 8.16.

**Table 8.16 Grading of traffic technicalities**

| | I-1-c | II-2-c | III-1-a |
|---|---|---|---|
| Capacity | 2 | 3 | 5 |
| Safety | 2 | 3 | 5 |

### 4) Others

Other items include noise and vibration during construction, noise and vibration after operation, aesthetic, community separation, possibility for future extension, effective land use as well as disaster prevention and ease of rescue operation in the event of a traffic accident. Similar to PIE, the results of the evaluation for each study is shown in Table 8.17.

The noise level of the representative cross section of each alternative after operation are summarized in Appendix 8.3 for reference purposes for the evaluation study on noise. The same figure can be applied to PYE because the road regulations of KLE and PYE is basically the same, even though the traffic conditions are different.

**Table 8.17 Analysis on various feature ( KLE )**

| ITEMS | | ALTERNATIVE | I-1-c Tunnel | II-2-c Tunnel | III-1-a Viaduct |
|---|---|---|---|---|---|
| Noise & Vibration under Construction Work | | | Pile driving for foundation will slightly affect residential area along KLE. | Pile driving for foundation will slightly affect residential area along KLE. | Pile driving for foundation will slightly affect residential area along KLE. |
| AFTER CONSTRUCTION | Environmental Impact | Noise & Vibration | The viaduct section beyond MRT has high tendency of noise pollution especially at high floor levels. | The viaduct section beyond MRT has high tendency of noise pollution especially at high floor levels. | The whole section beyond MRT has high tendency of noise pollution especially at high floor levels. |
| | | Aesthetic | Passage KLE near existing flats will give negative image to residents. | Passage KLE near existing flats will give negative image to residents. | The whole section will give a sense of oppression to the residents along the KLE. |
| | | Community Separation | Slight segregation among residents exist. | Slight segregation among residents exist. | Slight segregation among residents exist. |
| | Possibility for Future Extension | | Under ground structure such as tunnel severely restrict future extension. | Under ground structure such as tunnel severely restrict future extension. | Viaduct is usually permanent structure, however, adding lanes may not be impossible. |
| | Effectiveness on the Land Usage | | The land area above the tunnel can be used effectively. | The land area above the tunnel can be used effectively. | The land area under the viaduct can be used effectively. |
| | Disaster | Security of Traffic | Difficult to rescue activity in tunnel section. | Difficult to rescue activity in tunnel section. | Possibility of disaster extension is low but no obstruction to rescue activity. |

## 8.3.3 PYE

### 1) Economic aspects

The construction cost for PYE is as shown in Table 8.18. As is obvious from the Table, for all routes, the costs for I-a, II-c, III-c which are tunnels and semi-covered structures are 1.2 to 1.5 times higher than other viaduct and surface road projects. As opposed to this, the II-b project for Defu Avenue planned on surface ground is the most economical. However, as tunnels accounted for in extensions is 13% of the total and semi-covered structures for II-c and III-c accounts for only a low 27%, there is no radical difference in the construction costs for the various projects. The unit cost per metre for each project is shown below.

| | | |
|---|---|---|
| I-a | viaducts + tunnels + surface roads | S$ 370 Mil.(S$ 35700/m) |
| II-a | viaducts + surface roads | S$ 279 Mil.(S$ 27600/m) |

| | | |
|---|---|---|
| II-b | viaducts + surface roads | S$ 239 Mil.(S$ 23600/m) |
| II-c | Viaducts + semi-covered + surface roads | S$ 339 Mil.(S$ 33500/m) |
| III-a | viaducts + surface roads | S$ 280 Mil.(S$ 27300/m) |
| III-b | viaducts + semi-covered + surface roads | S$ 335 Mil.(S$ 32700/m) |

Compared to KLE, the unit cost per metre is around half for the following reasons. The interchange is small compared to the KLE. Furthermore, due to extensions, around more than 30% are surface roads. These costs include the interchange but excludes land acquisition, preliminary/mobilization and contingency costs.

**2) Construction aspects**

**Route I** (Alternative I-a)

Proposed route passing over PIE on viaduct, over the lines of Pelton Canal, turns to the north-east way, apart from the other 2 routes at the crossing of Paya Lebar Road, to travel along Airport Road until going under Airbase by tunnel. After through out of Airbase tunnel, the route crosses the Tampines Road by flyover or underground to enter the fish farm area at ground level until crossing over Serangoon River.

Viaduct construction works involving Pelton Canal requires working platform or troublesome diversion of waterway. However, on both sides of Pelton Canal, there is plenty of area for construction use. There is adequate spatial room also on both sides of Airport Road convenient for smooth construction of viaduct.

For the tunneling works inside the Air Base, presumed methods are open cut and cover method and NATM method, however the former method is under assumption in the Study. Tunneling length extends 1.4km and needs ventilation and a drainage facility. At the crossing construction to Tampines Road the current traffic is to be diverted onto detour.

Fish farm has been reclaimed with waste soil to the flat tablelands where ground level highway seems suitable. However unknown geological condition on the former sub-grade leaves selection pending.

A bridge across Serangoon River can be erected in the conventional cantilever method. Except for some unknown factor, there is not so difficult working item as to notice. Therefore, evaluated score is given 3 indicating "standard" ( refer to Appendix 8.3(4)).

**Route II** (Alternative II-a, II-b, II-c)

After deviating from Route I at the crossing to Paya Lebar Road, the Route II swinging its direction to the north is to take a course on Defu Avenue 1. Route II is proposed by 3 Alternatives; grade separation,i.e. viaduct, ground level or at-grade expressway, depressed or semi-covered tunnel.

After passing through Defu Avenue 1, the route flies over Tampines Road to go along on the right bank of Serangoon River and enter into the tableland area until crossing the River. While the route sections other than in Defu Avenue 1 are of common type of structures, the main theme in this route is how to pass the Defu Avenue 1 in 26 m wide through the Defu area. This area allows several design options with comparatively

## Table 8.18 Construction cost and maintenance cost ( PYE )

PYE(1)

Unit : Million S$

| | ITEMS | | UNIT | UNIT PRICE S$ | I-A Quantities | I-A Amount | II-A Quantities | II-A Amount | II-B Quantities | II-B Amount | II-C Quantities | II-C Amount |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CONSTRUCTION | EARTH WORK | | M^3 | 4 | 652,900 | 2.61 | 609,700 | 2.44 | 857,700 | 3.43 | 618,800 | 2.48 |
| | PAVEMENT | | M^2 | 40 | 84,670 | 3.39 | 79,060 | 3.16 | 111,220 | 4.45 | 80,240 | 3.21 |
| | ROADSIDE DRAIN | | M | 215 | 5,740 | 1.23 | 5,360 | 1.15 | 7,540 | 1.62 | 5,440 | 1.17 |
| | LANE MARKING AND TRAFFIC SIGNS | | M | 48 | 9,400 | 0.45 | 9,200 | 0.44 | 9,200 | 0.44 | 9,200 | 0.44 |
| | IMPACT GUARD RAILING | | M | 65 | 11,480 | 0.75 | 10,720 | 0.70 | 15,080 | 0.98 | 10,880 | 0.71 |
| | TREE PLANTING | | M | 120 | 9,400 | 1.13 | 9,200 | 1.10 | 9,200 | 1.10 | 9,200 | 1.10 |
| | CENTER DIVIDER(INC. MED.DRAIN) | | M | 160 | 2,870 | 0.46 | 2,680 | 0.43 | 3,770 | 0.60 | 2,720 | 0.44 |
| | STREET LIGHTING | | M | 173 | 9,400 | 1.63 | 9,200 | 1.59 | 9,200 | 1.59 | 9,200 | 1.59 |
| | FLYOVER STRUCTURE | | M^2 | 1,200 | 144,550 | 173.46 | 192,340 | 230.81 | 160,190 | 192.23 | 116,530 | 139.84 |
| | *DEPRESSED STRUCTURE* | *COVERD* | *M^2* | *2,600* | *46,900* | *121.94* | *0* | *0.00* | *0* | *0.00* | *0* | *0.00* |
| | | COVERD UNDER CANAL | M^2 | 3,380 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | | SEMI-COVERD | M^2 | 1,660 | 7,820 | 12.98 | 0 | 0.00 | 0 | 0.00 | 86,020 | 142.79 |
| | PEDESTRIAN BRIDGE | | EACH | 250,000 | 0 | 0.00 | 0 | 0.00 | 3 | 0.75 | 0 | 0.00 |
| | DEMOLITION | CONCRETE | M^3 | 0 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | | PAVEMENT | M^3 | 0 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | REMOVAL | PEDESTRIAN BRIDGE | EACH | 20,000 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | OTHERS | | | | | 16.00 | | 12.09 | | 10.36 | | 14.69 |
| | SUB TOTAL | | | | | 336.03 | | 253.92 | | 217.56 | | 308.45 |
| | PRE. CHARGE / MOBI.(10%) | | | | | 33.60 | | 25.39 | | 21.76 | | 30.85 |
| LAND ACQUISITION AND COMPENSATION | | PL | M^2 | | 41,850 | | 25,370 | | 25,940 | | 26,790 | |
| | | SL | M^2 | | 446,750 | | 398,060 | | 405,140 | | 415,760 | |
| SUB TOTAL | | | | | | 369.63 | | 279.31 | | 239.32 | | 339.30 |
| CONTINGENCY (10%) | | | | | | 36.96 | | 27.93 | | 23.93 | | 33.93 |
| TOTAL | | | | | | 406.59 | | 307.24 | | 263.25 | | 373.23 |
| MAINTENANCE COST (Annual Cost) *10^3 S$/Km | ABOVE GROUND | | | | | 10.2 | | 10.2 | | 10.2 | | 10.2 |
| | TUNNEL | | | | | 100.0 | | 100.0 | | 100.0 | | 100.0 |

PYE(2)

Unit : Million S$

| | ITEMS | | UNIT | UNIT PRICE S$ | III-A Quantities | III-A Amount | III-B Quantities | III-B Amount |
|---|---|---|---|---|---|---|---|---|
| *CONSTRUCTION* | *EARTH WORK* | | *M^3* | *4* | *637,000* | *2.55* | *657,500* | *2.63* |
| | PAVEMENT | | M^2 | 40 | 82,600 | 3.30 | 85,260 | 3.41 |
| | ROADSIDE DRAIN | | M | 215 | 5,600 | 1.20 | 5,780 | 1.24 |
| | LANE MARKING AND TRAFFIC SIGNS | | M | 48 | 9,300 | 0.45 | 9,300 | 0.45 |
| | IMPACT GUARD RAILING | | M | 65 | 11,200 | 0.73 | 11,560 | 0.75 |
| | TREE PLANTING | | M | 120 | 9,300 | 1.12 | 9,300 | 1.12 |
| | CENTER DIVIDER(INC. MED.DRAIN) | | M | 160 | 2,800 | 0.45 | 2,890 | 0.46 |
| | STREET LIGHTING | | M | 173 | 9,300 | 1.61 | 9,300 | 1.61 |
| | FLYOVER STRUCTURE | | M^2 | 1,200 | 191,750 | 230.10 | 115,050 | 138.06 |
| | DEPRESSED STRUCTURE | COVERD | M^2 | 2,600 | 0 | 0.00 | 0 | 0.00 |
| | | COVERD UNDER CANAL | M^2 | 3,380 | 0 | 0.00 | 0 | 0.00 |
| | | SEMI-COVERD | M^2 | 1,660 | 0 | 0.00 | 84,330 | 139.99 |
| | PEDESTRIAN BRIDGE | | EACH | 250,000 | | 0.00 | | 0.00 |
| | DEMOLITION | CONCRETE | M^3 | 0 | 0 | 0.00 | 0 | 0.00 |
| | | PAVEMENT | M^3 | 0 | 0 | 0.00 | 0 | 0.00 |
| | REMOVAL | PEDESTRIAN BRIDGE | EACH | 270,000 | 2 | 0.54 | 2 | 0.54 |
| | OTHERS | | | | | 12.10 | | 14.51 |
| | SUB TOTAL | | | | | 254.15 | | 304.77 |
| | PRE. CHARGE / MOBI.(10%) | | | | | 25.41 | | 30.48 |
| LAND ACQUISITION AND COMPENSATION | PL | | M^2 | | 6,680 | | 7,050 | |
| | SL | | M^2 | | 394,050 | | 413,800 | |
| SUB TOTAL | | | | | | 279.56 | | 335.25 |
| CONTINGENCY (10%) | | | | | | 27.96 | | 33.52 |
| TOTAL | | | | | | 307.52 | | 368.77 |
| MAINTENANCE COST (Annual Cost) *10^3 S$/Km | ABOVE GROUND | | | | | 10.2 | | 10.2 |
| | TUNNEL | | | | | 100.0 | | 100.0 |

few restriction from the construction viewpoint, except for disturbance to the current traffic during construction. Especially the construction works of underground structure at repeated crossings under Paya Lebar and Tampines Road is expected to bring traffic confusion. That is one disadvantage, therefore scoring is given 3 to viaduct and ground level alternative, 2 to depressed (refer to Appendix 8.3(5)).

**Route III** (Alternative III-a, III-b)

After deviating from Route I at the crossing to Paya Lebar Road, the Route III swings its direction to the north as Route II is to take a course on Hougang Avenue 3. Structure option proposes 2 alternatives; viaduct and depressed. Passing out of Hougang Avenue 3, this Route takes the same course as Route II. While Hougang Avenue 3 in 40m wide passes a residential area in favorable environment, this route alternative involves possible impact such as noise and traffic confusion, and dangerous accidents during construction carried out adjacent to public areas.

Alternative III-b proposing depressed structure embraces the construction difficulty at crossing under channel upstream of the Serangoon River with the disadvantage of unnecessary deepening of profile.

Improving this defect can be solved by diverting the channel, yet the troublesome works remains. Similarly, the depressed construction as the Route II at crossings to Paya Lebar Road and Tampines Road brings on traffic confusion. Appreciating the construction difficulty, the score is evaluated 3 to viaduct, 2 to depressed (refer to Appendix 8.3(6)).

Construction period for the Route III is estimated and evaluated as shown in Table 8.19.

**Table 8.19 Construction period and evaluation score**

| Alternative | Characteristics | Period (Day) | Period (Month) | Ratio to Average | Score |
|---|---|---|---|---|---|
| I | Airbase Tunnel | 18106 | 604 | 1.15 | 2 |
| II-a | Viaduct on Defu Ave. | 14345 | 478 | 0.91 | 4 |
| II-b | At grade on Defu Ave | 12817 | 427 | 0.81 | 5 |
| II-c | Depressed on Defu Ave. | 15048 | 502 | 0.96 | 3 |
| III-a | Viaduct on Hougang Ave. | 14339 | 478 | 0.91 | 4 |
| III-b | Depressed on Hougang Ave. | 19892 | 663 | 1.26 | 1 |

**3) Traffic aspects**

Regarding the comparative study on PYE, the following is the evaluation and results of the analysis from the viewpoint of traffic capacity and safety.

(1) Capacity

Similar to the case of KLE in 8.3.2, the evaluation on traffic capacity is done by comparing the relative gradings of the various alternatives using the grading of the traffic capacity ($INDEX_C$). The calculation method of $INDEX_C$ is same as 8.3.2 mentioned earlier.

The set values of Rci, Ici and Tci in each road region where the horizontal alignment changes are included in Appendix 8.4(3). The results of the capacity grading ($INDEX_C$) for each comparative study are shown in Table 8.20.

**Table 8.20 Evaluation of traffic capacity**

| | I - a | II - a | II - b | II - c | III - a | III - b |
|---|---|---|---|---|---|---|
| INDEX | 0.64 | 0.21 | 0.50 | 0.64 | 0.23 | 0.54 |

From the viewpoint of capacity, II-a and III-a are the best, followed by II-b, III-b, I-a, and II-c in that order.

(2) Safety

As is in the case of KLE in 8.3.2, evaluation of the relative traffic safety of each comparative study is done by using the grading on traffic safety from the viewpoint of traffic accident occurrence rate ($INDEX_C$). The calculation of $INDEX_C$ is similar to 8.3.2 mentioned earlier.

The set values of Rsi, Isi and Tsi in each road region where the horizontal alignment changes are included in Appendix 8.4(4). The results of the capacity grading ($INDEX_C$) for each comparative study are shown in Table 8.21.

**Table 8.21 Evaluation of traffic safety**

| | I - a | II - a | II - b | II - c | III - a | III - c |
|---|---|---|---|---|---|---|
| INDEX | 1.80 | 1.55 | 1.56 | 1.90 | 1.61 | 1.71 |

From the viewpoint of safety, II-1, II-b and III-a are the best, followed by III-b, I-a, and II-c in that order.

Based on the above study results, the grading and evaluation of traffic technicalities after operation was done as shown in Table 8.22.

**Table 8.22 Grading of traffic technicalities after operation**

| | I - a | II - a | II - b | II - c | III - a | III - b |
|---|---|---|---|---|---|---|
| Capacity | 2 | 4 | 3 | 2 | 4 | 3 |
| Safety | 2 | 4 | 4 | 2 | 4 | 3 |

### 4) Others

Other items include noise and vibration during construction, noise and vibration after operation, aesthetics, community separation, possibility for future expansion, effective land usage as well as disaster extension and use of rescue operation in the event of a traffic accident. There is also the problem of safety of the military airbase. As with other routes, the results of the evaluation of each alternative is shown in Table 8.23.

**Table 8.23 Analysis on various features ( PYE )**

| ITEMS \ ALTERNATIVE | | | I-a Tunnel | II-a Elevated | II-b At-grade | II-c Depressed | III-a Elevated | III-b Depressed |
|---|---|---|---|---|---|---|---|---|
| Noise & Vibration under Construction Work | | | The construction work under the airbase will have no effect on the residents along the PYE. | Pile driving for foundation will slightly affect the residential area along the PYE. | Earth work on Ave. will slightly affect the residential area along the PYE. | Excavation and driving piles will slightly affect the residents along the PYE. | Pile driving for foundation will have severe effect on residents along the PYE. | Excavation and pile driving will hava fairly severe effect on residents along the PYE. |
| AFTER CONSTRUCTION | Environmental Impact | Noise & Vibration | Traffic noise will be negligible along Hougang Road. | Traffic noise will be fairly severe to residents in flats along Hougang Road. | Traffic noise will be fairly severe to residents in flats along Hougang Road. | Traffic noise will be slight to residents along Hougang Road. | Traffic noise will be intolerable to the residents in the flats without noise shelter. | Traffic noise is slight to to the residents Hougang Road. |
| | | Aesthetic | Tunnel construction will hardly change the exsiting aesthetic. | The viaduct along Defu Avenue will give a sense of oppression to the residents. | Slight sense of opression to the residents along Hougang Road. | Negligible effect on residents along Hougang Road. | The viaduct along the Hougang Rd. will give a sense of oppression to the residents. | Slight sense of opression to the residents along Hougang Road. |
| | | Community Separation | No change in existing social activities in the residential area. | Fairly severe change in the existing social existing activities. | Severe change in existing social activities in the residential area. | Slight change in existing social activities in the residential area. | Fairly severe change in existing social activities in the residential area. | Slight change in existing social activities in the residential area. |
| | Possibility for Future Extension | | Under ground structure such as tunnel severely restrict future extension. | Viaduct is usuall permanent structure, however, expansion is possible. | A lot of space for future extension. | Under ground structure such as semi-covered structure restrict future extension. | Viaduct is usually permanent structure, however, expansion is possible. | Under ground structure such as semi-covered structure restrict future extension. |
| | Effectiveness the Land Usage | | The space above ground can be used effectively because of open area. | The space under the viaduct can be utilized effectively. | A wide road area of 10 lanes is an obstruction to effective utilization of land. | The space above ground can be used effectively because of open area. | The space under the viaduct can be utilized effectively. | The space above ground can be used effectively because of open area. |
| | Disaster | Security of Traffic | It is difficult to conduct rescue activity in the tunnel section. | The possibility of disaster extension is low and there is no obstruction to rescue activity | There is no obstruction to the rescue activities. | Rescue activities can be done on the upper open space. | The possibility of disaster extension is low and there is no obstruction to rescue activity. | Rescue activities can be done on the upper open space. |

## 8.4 Evaluation of Alternatives

Comparative evaluation with fixed variables and quantity was carried out with selected items from the various aspects in section 8.3. Although this evaluation cannot be compared on the same axis, the general evaluation for each alternative was tried using the weights and criteria of grading explained in sections 8.1 and 8.2. The results are as shown in Table 8.24 to 8.26. The maximum possible score for each alternative is 500, but there is no significance in the absolute value.

Based on those results, further studies will be done for each expressway.

## 8.4.1 PIE

There was a clear difference of 30 points between alternative I group (1-a - 1-d) and II group (II-1 - II-2). This is the direct result of the difference in gradings of construction costs and period of construction, which are based on the difference in content of the upgradings. With these results, as long as there are no great disparities in traffic capacity and safety, there will be no opposition against a surface expansion plan. There is also no particularly great merit in the plan to build new elevated structures. In conclusion, the proposition to add a further level to the present interchange which has 2 levels is not a feasible plan from the various points of view.

On the other hand, there was no great difference between the various plans implementing surface roads. This is quite natural in a sense. Alternative I group has almost identical conditions with the breaking down of the alternative is limited only to traffic management and except for traffic evaluation, these items by nature do not differ much. The results regarding the aspect of traffic management is noted in detail in 3) in 8.3.1. Alternative I-1-d whose content is slightly different from the initial, is evaluated to be the most efficient and is recommended.

**Table 8.24 Comprehensive evaluation of alternatives for PIE**

| ITEMS | | ALTERNATIVE | Weightage | I-1-a At-grade | | I-1-b At-grade | | I-1-c At-grade | | I-1-d At-grade | | II-1 Viaduct | | II-2 Viaduct | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UNDER CONSTRUCTION | Traffic Management | Capacity | 5 | 3 | 15 | 3 | 15 | 3 | 15 | 3 | 15 | 4 | 20 | 4 | 20 |
| | | Accessibility | 2 | 3 | 6 | 3 | 6 | 3 | 6 | 3 | 6 | 4 | 8 | 4 | 8 |
| | Construction | Construction Technic | 6 | 2 | 12 | 2 | 12 | 2 | 12 | 2 | 12 | 3 | 18 | 3 | 18 |
| | | Construction Period | 6 | 5 | 30 | 5 | 30 | 5 | 30 | 5 | 30 | 2 | 12 | 1 | 6 |
| | Environmental Impact | Noise & Vibration | 3 | 2 | 6 | 2 | 6 | 2 | 6 | 2 | 6 | 3 | 9 | 3 | 9 |
| | Initial Cost | Land Acqui. & Compensation | 6 | 3 | 18 | 3 | 18 | 3 | 18 | 3 | 18 | 3 | 18 | 3 | 18 |
| | | Construction | 15 | 4 | 60 | 4 | 60 | 4 | 60 | 4 | 60 | 2 | 30 | 1 | 15 |
| AFTER CONSTRUCTION | Traffic | Capacity | 8 | 3 | 24 | 2 | 16 | 3 | 24 | 4 | 32 | 4 | 32 | 2 | 16 |
| | | Safety | 8 | 3 | 24 | 4 | 32 | 3 | 24 | 4 | 32 | 3 | 24 | 3 | 24 |
| | Environmental Impact | Noise & Vibration | 8 | 3 | 24 | 3 | 24 | 3 | 24 | 3 | 24 | 2 | 16 | 2 | 16 |
| | | Aesthetic | 6 | 4 | 24 | 4 | 24 | 4 | 24 | 4 | 24 | 2 | 12 | 2 | 12 |
| | | Community Separation | 4 | 3 | 12 | 3 | 12 | 2 | 8 | 2 | 8 | 3 | 12 | 3 | 12 |
| | Maintenance Cost | Drainage | 8 | 2 | 16 | 2 | 16 | 2 | 16 | 2 | 16 | 3 | 24 | 3 | 24 |
| | Possibility for Future Extension | | 5 | 3 | 15 | 3 | 15 | 3 | 15 | 3 | 15 | 2 | 10 | 2 | 10 |
| | Effectiveness on the Land Usage | | 10 | 3 | 30 | 3 | 30 | 3 | 30 | 3 | 30 | 4 | 40 | 4 | 40 |
| TOTAL SCORE | | | 100 | | 316 | | 316 | | 312 | | 328 | | 285 | | 248 |

## 8.4.2 KLE

For KLE, there were clear differences in the grading between the alternatives. Alternative III-1-a which uses viaducts for the whole line has the highest grading followed by tunnel alternative I-1-c which intersects ECP with a viaduct. The lowest is alternative II-2-c which forms an interchange at ECP with underground structures. This can be said to be a matter of course in a certain sense. This is because an underground interchange structure is only an accepted alternative in areas with very high land prices where intensive use of land is an absolute condition. Where other factors are concerned, especially traffic safety, costs of construction and maintenance, etc, it has obvious disadvantageous and hence the low grading can be expected.

**Table 8.25 Comprehensive evaluation of alternatives for KLE**

| ITEMS | | ALTERNATIVE | Weightage | I-1-c Tunnel | | II-2-c Tunnel | | III-1-a Viaduct | |
|---|---|---|---|---|---|---|---|---|---|
| UNDER CONSTRUCTION | Traffic Management | Capacity | 3 | 2 | 6 | 3 | 9 | 5 | 15 |
| | | Accessibility | 2 | 2 | 4 | 3 | 6 | 5 | 10 |
| | Construction | Construction Technic | 4 | 2 | 8 | 2 | 8 | 3 | 12 |
| | | Construction Period | 4 | 2 | 8 | 1 | 4 | 5 | 20 |
| | Environmental Impact | Noise & Vibration | 3 | 4 | 12 | 4 | 12 | 4 | 12 |
| | Initial Cost | Land Acqui. & Compensation | 5 | 3 | 15 | 3 | 15 | 3 | 15 |
| | | Construction | 14 | 3 | 42 | 1 | 14 | 5 | 70 |
| AFTER CONSTRUCTION | Traffic | Capacity | 8 | 3 | 24 | 2 | 16 | 4 | 32 |
| | | Safety | 8 | 2 | 16 | 3 | 24 | 4 | 32 |
| | Environmental Impact | Noise & Vibration | 8 | 3 | 24 | 3 | 24 | 3 | 24 |
| | | Aesthetic | 8 | 4 | 32 | 4 | 32 | 3 | 24 |
| | | Community Separation | 4 | 4 | 16 | 4 | 16 | 4 | 16 |
| | Maintenance Cost | Ventilation & Drainage | 8 | 3 | 24 | 2 | 16 | 4 | 32 |
| | Possibility for Future Extension | | 6 | 3 | 18 | 2 | 12 | 4 | 24 |
| | Effectiveness on the Land Usage | | 10 | 4 | 40 | 4 | 40 | 3 | 30 |
| | Disaster | Security of Traffic | 5 | 2 | 10 | 2 | 10 | 4 | 20 |
| TOTAL SCORE | | | 100 | | 299 | | 258 | | 388 |

### 8.4.3 PYE

Judging from the general grading, there is little difference among the various alternatives for the PYE and every one of these projects has a possibility of advancing into the next phase. Starting from the high end of the grading, the viaduct alternative at Defu Avenue (II-a) comes first, followed by surface road (II-b), the military air base route (I-a) and the viaduct alternative at Hougang Avenue (III-a) in that order. The two remaining alternatives have a slight gap in grading with the rest. Alternative I-a, which is the original choice of PWD, is placed third. This is due to poor grading for surface roads and elevated structures in terms of economy in construction and maintenance costs as well as traffic management and capacity. As for the alternative to build semi-underground structures below Hougang Avenue, assuming the case where it is a condition to cross Hougang Avenue, except for the low grading for costs, it is excellent where environmental impact, effectiveness of land usage, etc is concerned. This alternative should certainly be considered.

**Table 8.26 Comprehensive evaluation of alternatives for PYE**

| ITEMS | | ALTERNATIVE | Weigh-tage | I-a Tunnel | II-a Elevated | II-b At-grade | II-c Depressed | III-a Elevated | III-b Depressed |
|---|---|---|---|---|---|---|---|---|---|
| U E R C S T R U C T I O N | Traffic Management | Capacity | 4 | 3 : 12 | 3 : 12 | 3 : 12 | 3 : 12 | 2 : 8 | 2 : 8 |
| | Construction | Construction Technic | 2 | 3 : 6 | 3 : 6 | 3 : 6 | 2 : 4 | 3 : 6 | 2 : 4 |
| | | Construction Period | 3 | 2 : 6 | 4 : 12 | 5 : 15 | 3 : 9 | 4 : 12 | 1 : 3 |
| | Environmental Impact | Noise & Vibration | 3 | 5 : 15 | 3 : 9 | 4 : 12 | 3 : 9 | 1 : 3 | 2 : 6 |
| | Initial Cost | Land Acqui. & Compensation | 6 | 4 : 24 | 3 : 18 | 2 : 12 | 3 : 18 | 3 : 18 | 3 : 18 |
| | | Construction | 15 | 2 : 30 | 4 : 60 | 4 : 60 | 2 : 30 | 4 : 60 | 2 : 30 |
| A F T E R C O N S T R U C T I O N | Traffic | Capacity | 8 | 2 : 16 | 4 : 32 | 3 : 24 | 2 : 16 | 4 : 32 | 3 : 24 |
| | | Safety | 8 | 2 : 16 | 4 : 32 | 4 : 32 | 2 : 16 | 4 : 32 | 3 : 24 |
| | Environmental Impact | Noise & Vibration | 8 | 5 : 40 | 2 : 16 | 2 : 16 | 4 : 32 | 1 : 8 | 3 : 24 |
| | | Aesthetic | 8 | 5 : 40 | 3 : 24 | 3 : 24 | 4 : 32 | 2 : 16 | 3 : 24 |
| | | Community Separation | 4 | 5 : 20 | 2 : 8 | 1 : 4 | 3 : 12 | 2 : 8 | 3 : 12 |
| | Maintenance Cost | Ventilation & Drainage | 8 | 1 : 8 | 3 : 24 | 4 : 32 | 2 : 16 | 3 : 24 | 2 : 16 |
| | Possibility for Future Extension | | 5 | 3 : 15 | 4 : 20 | 4 : 20 | 3 : 15 | 3 : 15 | 2 : 10 |
| | Effectiveness on the Land Usage | | 10 | 5 : 50 | 2 : 20 | 1 : 10 | 3 : 30 | 3 : 30 | 4 : 40 |
| | Disaster | Security of Traffic | 5 | 1 : 5 | 3 : 15 | 5 : 25 | 2 : 10 | 3 : 15 | 2 : 10 |
| | | Security of Airbase | 3 | 2 : 6 | 3 : 9 | 3 : 9 | 3 : 9 | 4 : 12 | 4 : 12 |
| TOTAL SCORE | | | 100 | 309 | 317 | 313 | 270 | 299 | 265 |

## 8.5 Determination of Advantageous Alternatives

This section narrows down the selection of alternatives with high priority in the Phase II study based on the general evaluation results in section 8.4.

### 8.5.1 PIE

For this expressway, it is obvious from the general evaluation results that the eventual alternative to be selected from will be those which calls for widening of surface roads. The problem is selecting from among these alternatives. Under the assumption that the road demand in 2010 is close to the figure projected in this study, alternative I-1-d is recommended. However, if the rise in demand is to slow down, then alternative I-1-a or I-1-b will also be sufficient to meet the needs. As an alternative has to be selected here by some means to proceed to the Phase II Study, each alternative was ranked as follows.

*The conclusion reached is the implementation of a schematic design* centering around alternative I-1-a. Studies are also to be made to explore the possibility of installing on-ramps in the direction of Jurong at Kim Keat and also the possibility of changing over to alternative I-1-b. In other words, until the year 2000, during which the traffic volume is thought to remain low, alternative I-1-b, which separates high speed traffic and low speed traffic, is the most effective way of dealing with the problem. Switching over to alternative I-1-a which has a high degree of freedom, at the point where the traffic volume exceeds that of the low speed traffic can be expected to bring about smooth road traffic from an overall point of view. However, with the traffic volume projected in 2010, is can be predicted that traffic management will again become impossible. Therefore as far as the situation can be predicted, the following methods of handling the problem can be foreseen. Management of on-traffic in the direction of Jurong can be distributed to 2 locations in Toa Payoh and Kim Keat, with the Kim Keat side handling the bulk of the traffic. Restricting the Toa Payoh off-ramp and the Kim Keat on-ramp in the direction of Changi to 1 lane or decreasing the number of lanes under alternative I-1-a or I-1-b can also be imagined.

Hence, with the assumption that the possibility of conversion is also to be studied, it is recommended that alternative I-1-d be the subject of the Phase II Study.

### 8.5.2 KLE

With KLE, there is a clear difference in the general evaluation scores of the various alternatives and compared to other routes, it is also the easiest to recommend an alternative for Phase II Study. As mentioned also earlier in 8.4, alternative II=2-c with its underground interchange has obvious disadvantages where traffic safety, possibility of conversion of land usage and construction and maintenance costs are concerned. Hence it is not considered and alternative I-1-c and III-1-a are the 2 alternatives selected for Phase II Study.

### 8.5.3 PYE

This expressway has very close general evaluation scores among the alternatives. All are qualified as competitive alternatives. However on the whole, the route using Defu Avenue has the highest score with its greatest flexibility among the alternatives to respond to the various problems that may arise. Although the general evaluation result is strictly adhered to, as the surface road plan in this route has a low score of only 1 for community separation and effective usage of land, this route has to be excluded. The 2 routes from alternative I-a which uses Defu Avenue with viaducts and passes through the military air base are selected.

# CHAPTER 9

# PRELIMINARY DESIGN

# CHAPTER 9 PRELIMINARY DESIGN

## 9.1 Design Conditions

### 9.1.1 Geometric Standard

Geometric Design Standard is basically determined by design speed. As such, horizontal radius curve, vertical gradient and stopping sight distance are all directly related to Design speed. Besides, Lane width, Shoulder width and Median width are also affected by Design speed.

Singapore Standards are applied for Geometric design standard. In the case where Singapore Standards are not specified, standards of other countries are used as reference and decisions are made after discussions and confirmation with PWD.

The Geometric Design Standard is shown in Table 9.2 and 9.3.

**1) Design speed**

Design Speed based on the type of roads available is classified into the following types :

**Table 9.1 Adopted design speed**

| Category | Recommended Standard (km/h) |
|---|---|
| Expressway Throughway | 80 |
| Interchange All Ramps | 60 |
| ON/OFF Ramp slip type | 50 |
| ON/OFF Ramp loop type | 40 |

**2) Typical cross section**

Typical Cross Sections are shown in Fig. 9.1 and Fig. 9.2.

**3) Right of way**

Right-of-way(ROW) is determined with the following factors taken into consideration:

a) The land use situation,terrain condition, future development plan, space for maintenance etc, along the expressway.

b) As ROW will have great impact on land acquisition and compensation, it has to be determined with care. The ROW is shown in the Typical Cross Section in Fig. 9.1 and Fig. 9.2. The minimum width of ROW, which is applicable to KLE and PYE, is shown in Table 9.4.

Table 9.2 Expressway geometric design standard

(Design speed 80 km/h for throughway)

| Element | Unit | Design Speed 80km/h Throughway | 60km/h IC All Ramps | 50km/h IC Slip Type | 40km/h IC Loop Type |
|---|---|---|---|---|---|
| Terrain | - | Flat | Flat | Flat | Flat |
| Lane Width | m | 3.70 | 3.70 | 3.70 | 3.70 |
| Outer Shoulder Width | m | 2.75 | 2.00 | 2.00 | 2.00 |
| Inner Strip Width | m | 0.90 | 0.30 | 0.30 | 0.30 |
| Median Width | m | 4.00 | 2.50 | 2.50 | 2.50 |
| Crossfall of Carriageway in Tangent Section | % | 2.78 | 2.78 | 2.78 | 2.78 |
| Minimum Radius (Horizontal Curve) | m | 300 | 125 | 85 | 50 |
| Maximum Gradient | % | 4.00 | 5.00 | 5.50 | 6.00 |
| Stopping Sight Distance | m | 120 | 80 | 55 | 40 |
| Minimum Vertical Clearance above Road | m | 5.40 | 5.40 | 5.40 | 5.40 |
| Acceleration Lengths without Taper: | | | | | |
| Single-lane Entrance Terminal | m | - | 150 | 160 | 170 |
| Two-lane Entrance Terminal | m | - | - | - | - |
| Taper Length | m | - | 70 | 70 | 70 |
| Deceleration Lengths without Taper: | | | | | |
| Single-lane Entrance Terminal | m | - | 90 | 100 | 110 |
| Two-lane Entrance Terminal | m | - | - | - | - |
| Taper Length | m | - | 70 | 70 | 70 |

Table 9.3 Throughway geometric design around interchange

(Design speed 80 km/h for throughway)

| Element | Unit | Recommended Standard |
|---|---|---|
| Horizontal Curve Radius | m | 1100 |
| Vertical Curve Radius | | |
| Type Crest | m | 12000 |
| Type Sag | m | 8000 |
| Maximum Gradient | % | 3.00 |

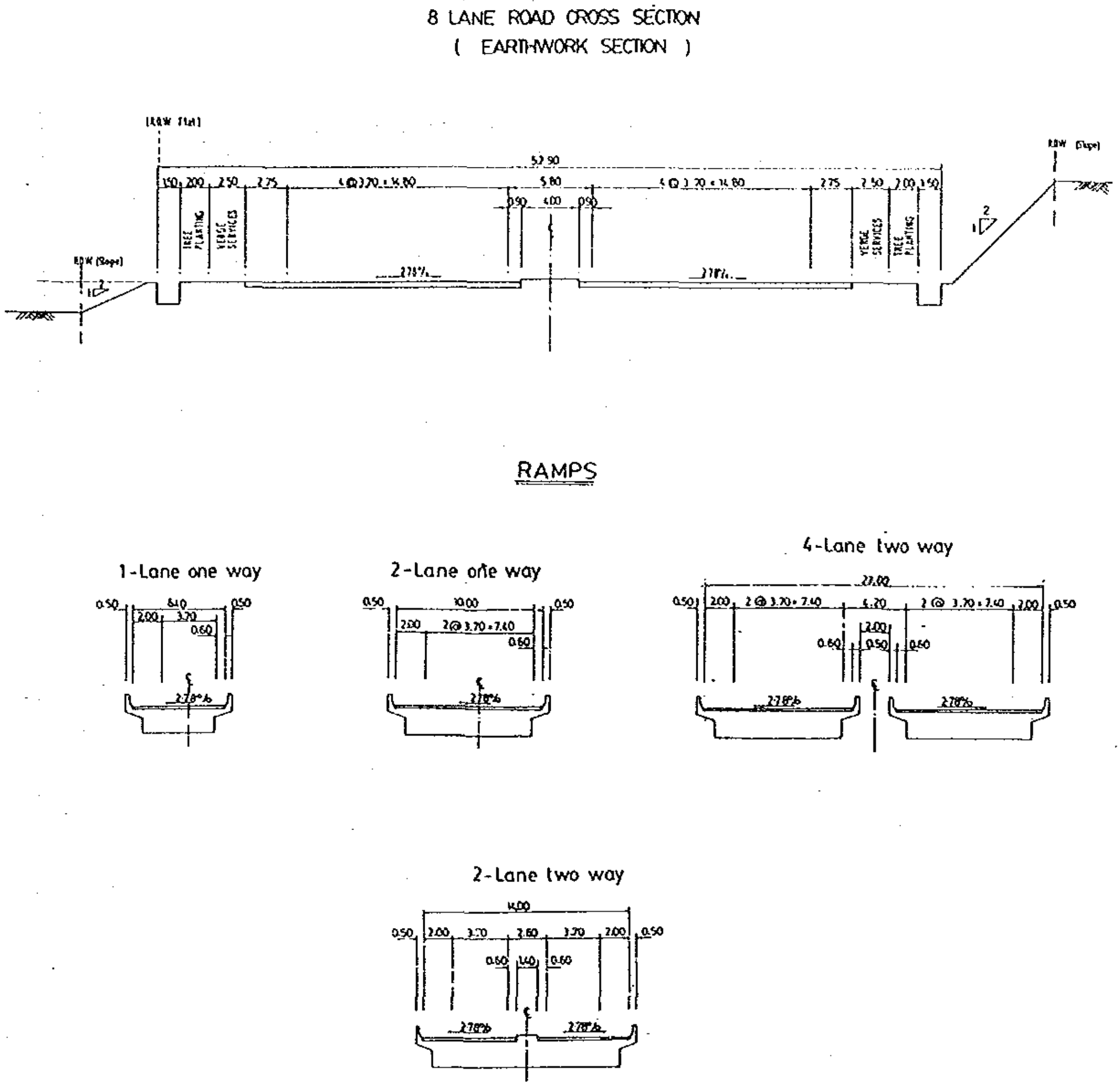


Fig. 9.1 Typical cross section for PIE

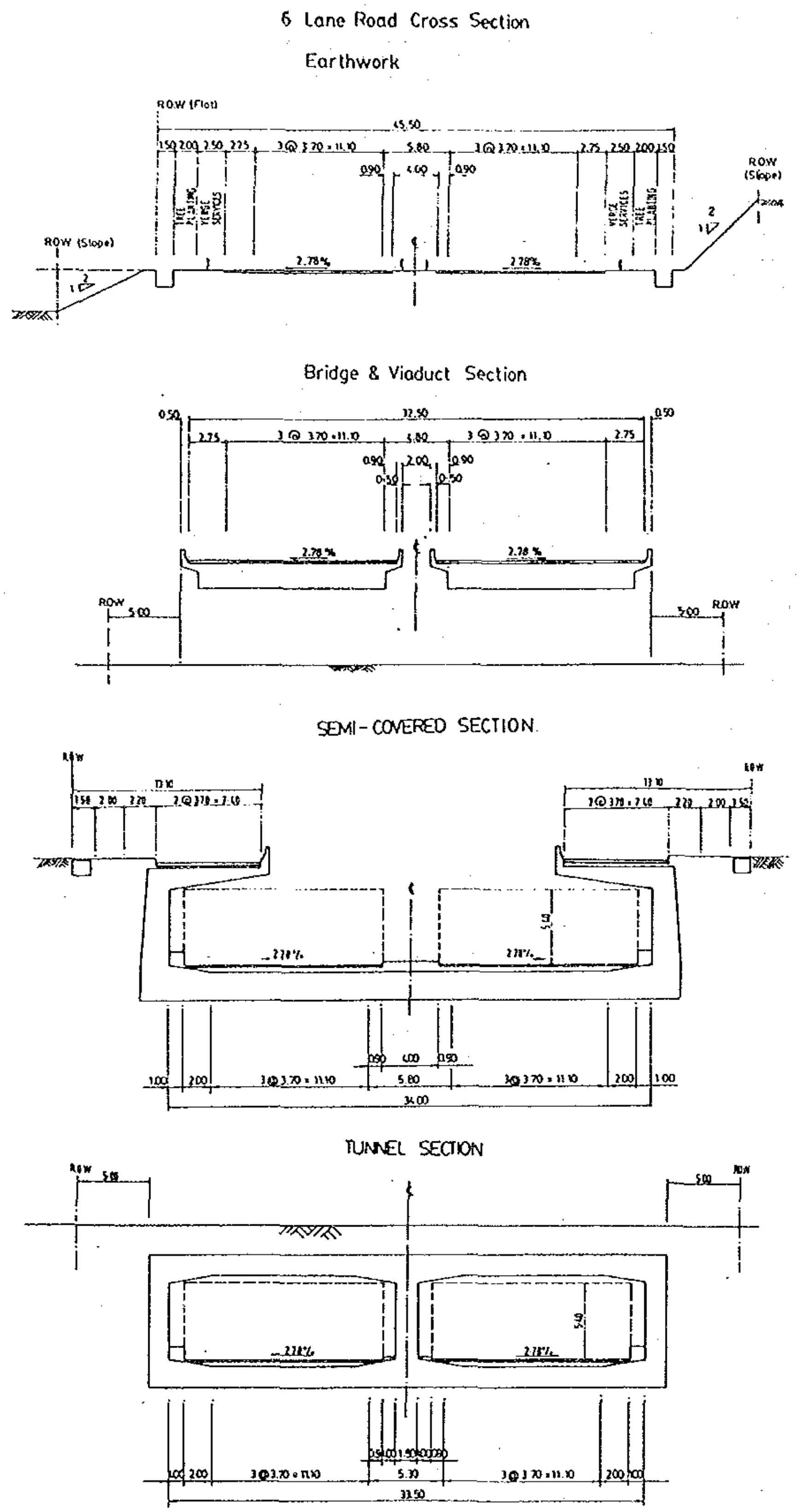


Fig. 9.2 Typical cross section for KLE and PYE

Table 9.4 **Minimum ROW width**

| Construction of the Expressway | | Recommended Min. ROW Width (m) |
|---|---|---|
| At grade | 6-Lane | 44.5 |
| Flyover | 6-Lane | 43.5 |
| Tunnel and Semi-covered | 6-Lane | 46.5 |

### 9.1.2 Structural Standard

Currently, Singapore Standards and BS5400 (described below) are mainly used as the Structural Design Standard in this study especially for carrying out the Preliminary design in Phase II (refer to Appendix 9.1).

| | |
|---|---|
| Singapore Standards: | Code of Practice CP4 Foundations<br>Code of Practice CP11 Demolition<br>Code of Practice CP18 Earthworks |
| British Standards: BS5400 | Part 2 Specification for loads<br>Part 3 Code of practice for design of steel bridges<br>Part 4 Code of practice for design of concrete bridges |

### 9.1.3 Drainage Standards

For the design of drainage system, rainfall intensity was determined in accordance with the probability based on the following conditions.

| Drainage System | Return Period |
|---|---|
| Surface Drainage | 5 years |
| Conduit & Duct | 25 years |

## 9.2 Geometric Design of Expressways

In a design of expressway, the difference in the character of improvement and new construction, the restricted available land and other features that each expressway has, are generally taken into consideration. The common consideration for the expressways is as follows:

- To apply the design standards so as to ensure efficient traffic flow and traffic safety at the desirable traveling speed.
- To apply alignment that the driver can easily foresee.
- *To consider the combination of horizontal and vertical alignments* to ensure comfortable driving.

Preliminary designs are conducted using various topographic maps as follows ;

| | | |
|---|---|---|
| - PIE | PIE/BKE IC - PIE/Thomson IC | : 1/2,000 |
| | PIE/Thomson IC - PIE/CTE IC | : 1/1,000 |
| - KLE | KLE/ECP IC - KLE/PYE/PIE IC | : 1/2,000 |
| - PYE | KLE/PYE/PIE IC - PYE/TPE IC | : 1/2,000 |

### 9.2.1 PIE

The PIE could be divided in broad terms into 2 sections as shown in Fig. 9.5. One is from PIE/BKE IC to PIE/Thomson IC and the other is PIE/Thomson IC to PIE/CTE IC. Possibility of future improvement to existing structures and the adoption of construction methods which would least disturb the traffic flow, were paid special attention during the Study.

**1) PIE/BKE IC-PIE/Thomson IC**

There are no facilities avoided along the expressway between PIE/BKE IC and PIE/Adam Rd.IC and the existing horizontal alignment is fairy good. Therefore one lane widening on each side of existing road was taken up for this section.

The distance between the noses of PIE/Eng Neo IC and PIE/Adam IC is about 950m and the gradient of the main through way on the stretch is 4.3%. The rate of the vehicles which use the first lane of the section is very high. These conditions are now bringing traffic confliction in merging section of PIE/Adam IC. Considering the above situation the number of lanes on the stretch is proposed to be 5. Consequently the distance between the taper ends of both interchanges is secured to be 600m.

PIE/Adam Road IC is presently a half clover type interchange. On the south side of the interchange there is a private land. The improvement works leading to the south and widening of the both sides require to purchase additional land.

Meanwhile, on the main through road below the present Adam Road bridge, a speed changing lane for ramp is included on both sides. By using this space and making width of median strip and road shoulder smaller, the Study Team recommended that the main through road could be made 4 lane for each direction. Therefore, the alternative on ramps were shifted to behind of the existing bridge abutments in box culverts. Eventually the possibility of traffic accident and the obstruction of smooth traffic during the improvement works could be reduced. The width of median strip would be reduced to 3.2 m (presently 4.0m) and that of shoulder to 1.85 m (presently 2.5m).

The section between PIE/Adam Road IC and PIE/Mt.Pleasant IC was treated in a same way to add one lane each on both sides since there is no facility as control points.

The main through road at the PIE/Mt. Pleasant IC was improved by four additional new lanes on the north side of the existing road since the horizontal alignment is not favorable and the improvement of the existing bridge is not easy. The radius of the main through road was improved to a 400m rather than existing less than 300m.

Some sections of PIE have unfavorable vertical alignment though, the Study Team did not propose to improve the sections considering a huge amount of work on structures and interchanges and disturbance on traffic during construction.

### 9.2.2 KLE

KLE, which starts from the 14 km point of ECP and ends at the interchange at the PIE, has a road length of about 3km as shown in Fig. 9.3. The land use along the route is, from the ECP side, waste land, small scale industries, low commercial establishments, housings, medium to tall rise housing establishments, other housings and primary and secondary schools. Future land use will be almost the same according to the Master Plan, except for both sides of Geylang River that has been planned for industrial area.

The area between Mountbatten Rd. and Sims Av. is already designated as safeguarded area. The construction of KLE has already been considered prior to construction of the MRT viaducts. The position of crossing with the MRT is presently almost fixed. The control points for the route selection are the distance from the ECP/Fort Rd. IC and the Benjamin Sheares Bridge on the ECP and the row of medium rise houses east of Geylang Lorong 4.

**1) Route-I**

The Route-I (Tunnel Alternative) passes through the ECP and Geylang River by bridges, the Kallang Park by a tunnel, Nicoll Highway, Sims Av. and MRT by semi-depressed and the PIE by a viaduct.

A sufficient distance is required to transfer the road from the bridge over the Geylang River to the tunnel under the Kallang Park. For the entrance of the tunnel, it is desirable to keep the horizontal alignment as straight as possible. It was found to be not possible to maintain necessary distance if the radius were large. During the Phase I study, an alignment using a radius of 400m and an gradient of 4 percent were conceived though, those figures were made to more comfortable 600m and 3 percent taking into consideration traffic safety. The tunnel portal was consequently set further back into the parking space of the park.

Many points were taken into consideration in designing of vertical

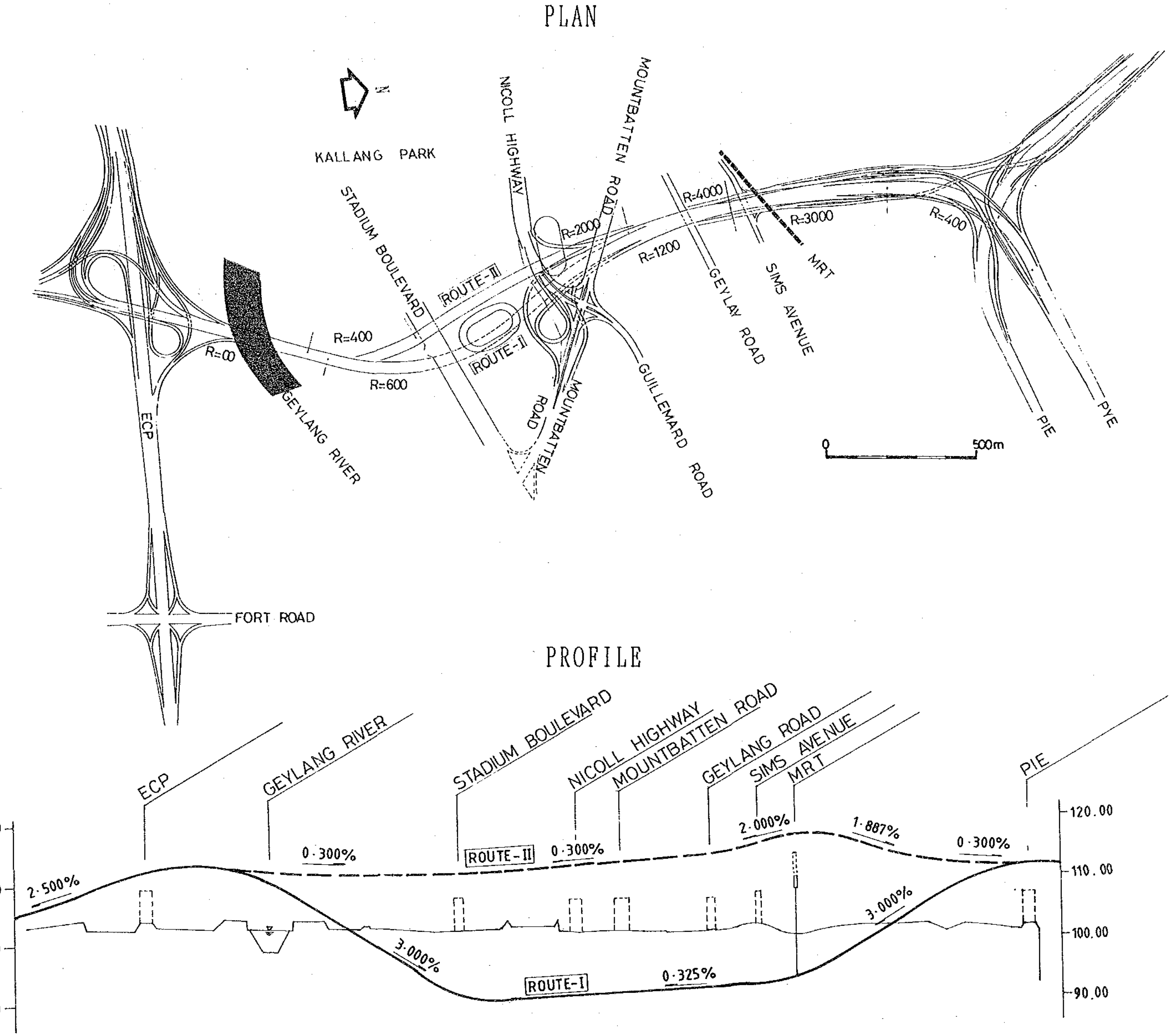


Fig. 9.3 Route alternatives for KLE

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alignment as follows:

- The clearance height of the bank of Geylang River should be more than 3.5m above the ground level considering maintenance work.
- Head room clearance for carriageway (5.4m), ventilation facility and traffic sign(1.8m), thickness of top slab(1.2m) and covering soil depth(2m) have to be provided. The proposed formation must be deeper than 10.5m below the ground level for the tunnel section.
- The footing of the MRT must not be affected.
- The proposed height of main throughway road of KLE should be high enough above the existing PIE while considering girder depth.
- The longitudinal gradient is to be less than 3% in the tunnel section and vicinity of interchanges.

**2) Route-II**

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

A horizontal alignment of as near to straight line as possible was adopted so that there would be no extra space left. A vertical alignment was planned to secure enough space underneath in the park giving careful consideration to aesthetic aspect and to be high enough over MRT to clear the train and to provide the maintenance allowance.

### 9.2.3 PYE

The PYE starts from the KLE/PYE/PIE IC and ends at the Tampines Expressway(TPE) as shown in Fig. 9.4. It is approximately 9km long. The expressway passes over Pelton Canal and is connected with both Paya Lebar Rd. and Tampines Rd.

Land use along the planned route is : between PIE and Paya Lebar Rd. is already a developed area, between Paya Lebar Rd. and Hougang Rd. is relatively empty industrial estates, between Hougang Rd. and Tampines Rd. is a low rise industrial estates, and between Tampines Rd. and PYE/TPE IC is a fish farming area, reservoir and refuse dumping area. The future land use between PIE and Tampines Rd. is not different from the present usage. Between Tampines Rd. and Tampines Expressway is an agriculture site but a part of it might be changed to industrial estates later.

**1) PIE-Paya Lebar Road**

The control points for the planning of horizontal alignment are the existing buildings along the road. In the Phase I, horizontal alignment is planned to satisfy the geometric standards; therefore, the Mattar Primary School and the private land on the right bank of the Canal are part of the route. In the Phase II the alignments were shifted to avoid such buildings to meet the PWD's requirement. Eventually a radius of 300m which is an absolute value, was used. Also PWD had indicated to avoid a flyover bypass at the Paya Lebar Rd. and Airport Rd.

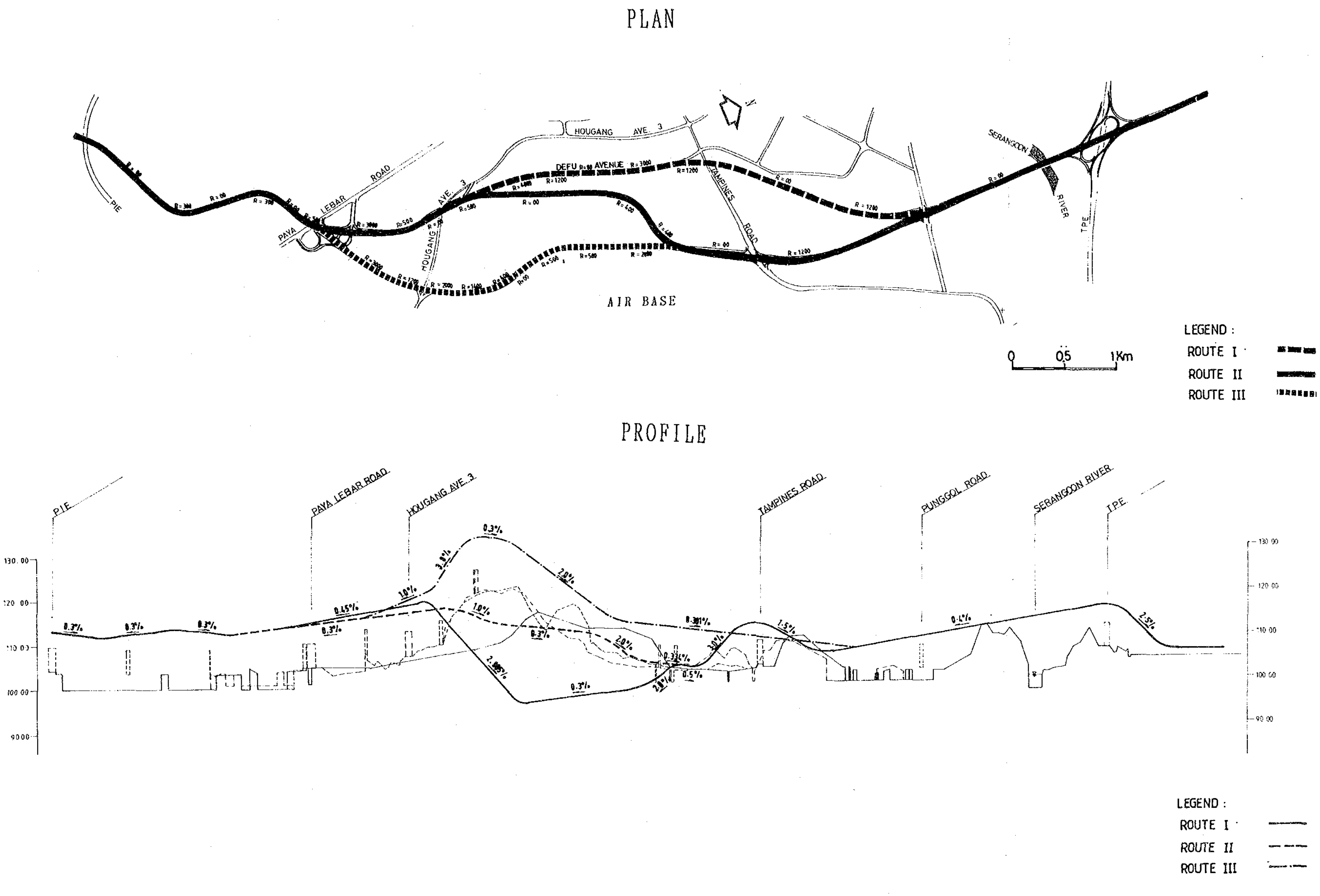


Fig. 9.4 Route alternatives for PYE

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intersection, thus the route is shifted.

The points considered in planning of vertical alignment were to ensure the head room clearance at intersections and to keep favorable height above the ground which shall be between 10-12m for aesthetical reason.

Between Paya Lebar Road to Tampines Road, 3 routes have been studied.

**2) Route-I**

Route-I passes over the Airport Rd. by a viaduct and the Air Base by tunnel and reaches Tampines Rd. at the north of Kim Chuan treatment.

The control points in planning horizontal alignments are the Kim Chuan Sewerage Treatment Plant, buildings in the Air Base and the Air Base sewerage pipeline.

The point considered in the vertical alignment planning is to have an favorable aesthetical aspect. The piers of viaduct above the Airport Road was designed to be Y-shaped and the proposed height was kept more than 12.5m above the existing road. The longitudinal gradient in the tunnel section is the same as KLE which is less than 3%.

**3) Route-II**

Route-II swerves from the Route-I before Paya Lebar Rd. and passes over the pipeline on the north of the Tai Seng Industrial estate, crossing Hougang Av. 3 and the green belt at the north of the Air Base; then joins the Route-I before Tampines Rd..

The consideration in the horizontal alignment planning was placed on the *points to keep expressway within the green belt and not to affect the* SBS bus depot operation.

The control points in vertical alignment setting are; to keep the proposed height at the same level as the Air Base, to ensure the height clearance of 5.4m for vehicles below viaducts at Kim Chuan Rd.

**4) Route-III**

Route-III swerves from the Route-II before Hougang Ave 3 and passes Defu Ave., Tampines Rd. and Serangoon River and then joins the Route-I at the planned location of the Punggol IC. The locations considered during horizontal alignment setting are the SBS bus depot. Its operation was not disturbed.

The considerations in vertical alignment planning are to ensure the space for buses into the SBS depot. The Y-shaped pier on Defu Ave. 1 were kept above ground over 12.5m from the viewpoint of aesthetical consideration.

**5) Tampines Rd.-TPE**

Between Tampines Road to the connection at TPE, it will pass through inside a future New Town, thus there is no control point in planning horizontal alignment. Serangoon River Crossing is to be intersected at around right angle.

The control point in vertical alignment is the connecting way of the *PYE/Punggol IC and PYE/TPE IC.*

### 9.3 Preliminary Design of Interchanges

Preliminary design of interchanges are conducted using 2 kinds of topographic maps by expressway as follows:

- PIE for all the interchanges : 1/1,000
- KLE and PYE for all the interchanges : 1/2,000

#### 9.3.1 PIE (refer to Fig.9.5)

The length for acceleration and deceleration lanes are corrected with the gradient of the stretch on which the interchanges are located, as shown in Table 9.5.

**Table 9.5 Correction coefficient for the length of acceleration and deceleration lane**

| Gradient of main way (%) | 0<Cf<2 | 2<Cf<3 | 3<Cf<4 | 4<Cf<6 |
|---|---|---|---|---|
| Deceleration lane in ascent | 1.0 | 1.1 | 1.2 | 1.3 |
| Deceleration lane in descent | 1.0 | 1.2 | 1.3 | 1.4 |

**1) PIE/BKE IC**

This interchange connects two expressways ; Pan Island Expressway (PIE) and Bukit Timah Expressway (BKE). The traffic analysis showed that all the ramps would have enough capacity for demand by having two lanes only. Those which did not meet this condition was the On ramp from Jurong direction to BKE. The ramp was recommended to be added one more lane in order to satisfy the traffic demand in the year 2010. The others have two lanes in the freeway section but the number of lanes are reduced to one lane at the noses. Those ramps also were recommended to add one lane up to the end of accelerating and decelerating zones.

**2) PIE/Eng Neo IC**

This interchange is a standard trumpet type interchange (Loop section is used as on ramp). Presently, on and off ramps towards Changi direction and on ramp towards Jurong direction have one lane. The Off ramp towards Jurong direction has two lanes. The off ramp towards Changi was improved according to the future forecast of traffic volume.

The present speed changing lanes are geometrically poor structure, and therefore several improvements were recommended such as ; the length of acceleration and deceleration lanes, the number of lanes, and longitudinal gradient. Since the length of on and off ramps towards Jurong direction is very short, the traffic flow into the expressway or access road are under highly unfavorable condition. From the viewpoint of traffic safety, the distance for deceleration and acceleration were lengthened and the decrease of joining angle was recommended.

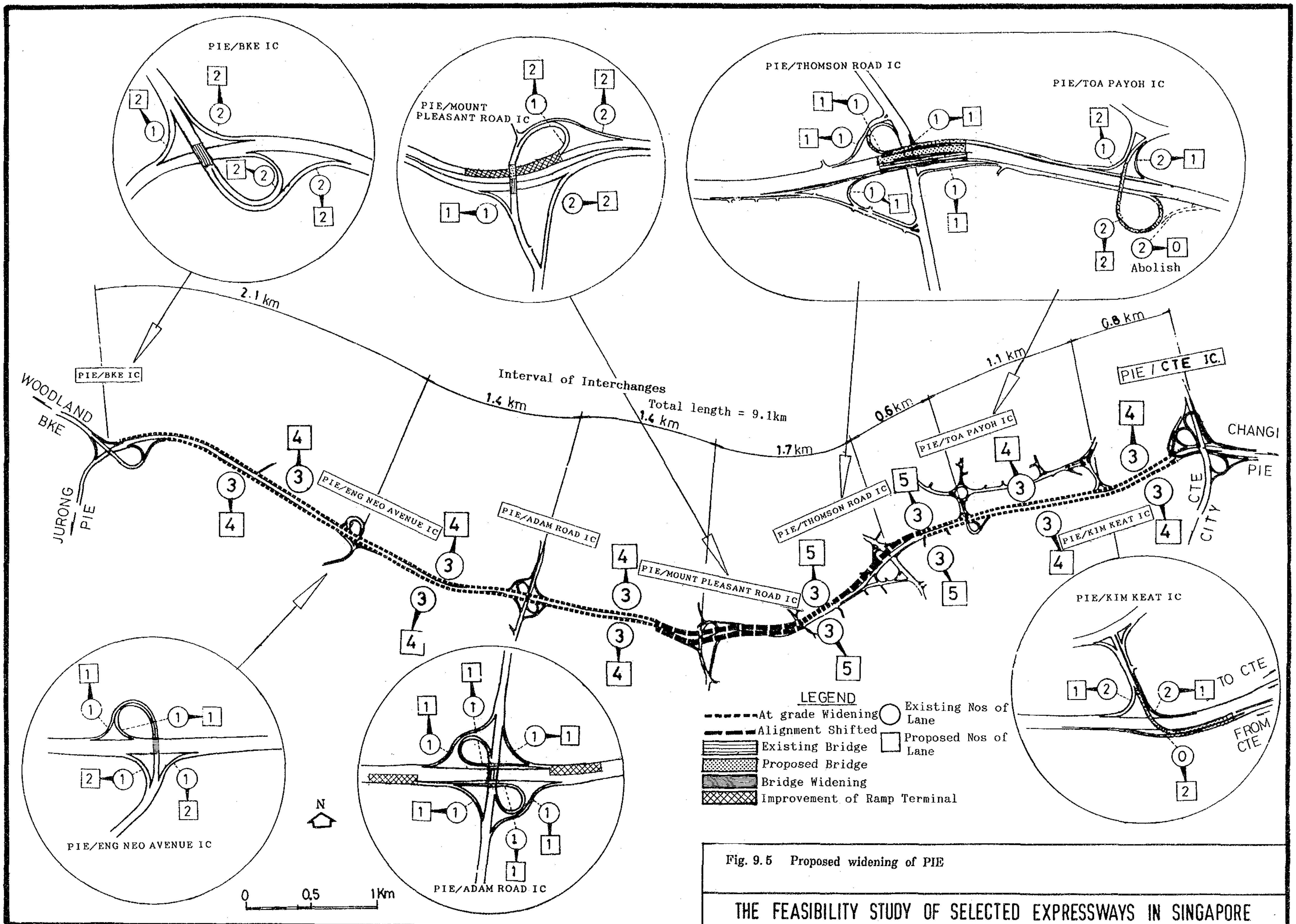


Fig. 9.5 Proposed widening of PIE

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**3) PIE/Adam IC**

There are deficiencies in this interchange such as small length for accelerating lanes and S-curves inserted in the off ramp. All the existing ramps have one lane which will be enough for the future traffic demand. Therefore there is no change in the number of lanes. Since the improvement of the S-curves require additional acquisition of private properties, only the improvement of speed varying zone is proposed. Continuous merging from the ramps into the main route was improved by introduction of merging lane which would enable ramp flows to merge first before going into the main flow.

**4) PIE/Mt. Pleasant IC**

This interchange is unfavorable since the radius of main through road is very small 300m and the on and off ramps are situated after the ramp viaduct. The off ramp of the west bound is a loop type and do not have enough decelerating lane length. The off ramp was recommended to be moved before the ramp viaduct and the radius of main through road was improved to 400m accompanied by additional lanes. It would require a good amount of investment to acquire additional land to improve the type of ramps and the recommendation was made only to secure enough length for deceleration of traveling speed from 80km/h to 40km/h. The traffic analysis showed the future demand to be about 70 percent of the present capacity of ramps.

**5) PIE/Thomson IC to PIE/Kim Keat IC**

There are four interchanges in a short distance between the PIE/Thomson IC and the PIE/CTE IC which creates enough trouble on top of the large flow of traffic, continuous merging and diverging, and existence of bus stops. The whole road network have to be integrated in a study instead of dealing with interchanges one by one. The sections of both east and west bound between the PIE/Thomson IC and the PIE/Toa Payoh IC and the east bound between the PIE/Kim Keat IC and PIE/CTE IC show worst weaving of traffic. The existing traffic flow at the roundabout at the north of PIE/Toa Payoh IC is 7,000 at the peak hour which is almost the capacity of the roundabout and it was recommended to take some measure to reduce the traffic into it.

During the Phase I study, the team recommended to open a new on ramp of west bound at the Kim Keat IC, instead of it at the PIE/Toa Payoh IC. Further study revealed that the off ramp of west bound at the PIE/Toa Payoh IC was difficult to be reconstructed and was recommended to move it to the PIE/Kim Keat IC. This caused new weaving problem at the on ramp from the CTE. It was also recommended to align the on ramp outside of the off ramp and to make the merging after the ramp traffic diverged. The traffic of off ramp of east bound at the PIE/Toa Payoh IC was recommended to be diverged first with the off ramp at PIE/Thomson IC. The west bound traffic between the PIE/Toa Payoh IC and PIE/Thomson IC would be made more comfortable by making the weaving lane outside of divider. The resulting effects from those measures would also ease the traffic at the roundabout near the PIE/Toa Payoh IC.

**6) PIE/Kim Keat IC**

Since the new bridge would cross over the PIE diagonally by a curve, it should be a two span PC precast girder with a support at the median. The sub-structure should be a cross head type. The on ramp from the CTE should use a new slab over the canal. The function of the canal should be retained by erecting the structures outside of it.

### 9.3.2 KLE

In the KLE there are 3 interchanges, KLE/ECP IC, KLE/Nicoll IC and the KLE/PYE/PIE IC.

#### 1) KLE/ECP IC

The location of the interchange was between the ECP/Fort Rd. IC and Benjamin Sheares bridge, and therefore, there were some issues solved such as the distance for diverging to the ECP/Fort Rd. IC and difficulty in extending interchange into the bridge proper. Other conditions were the superior traffic flow on the KLE and west bound ECP and less restriction in land use.

To the south of ECP, the KLE is connected to Marina South, hinterland of which has a small area. As described above, due to the restriction of ECP, the fundamental design is to maintain the necessary distance for changing speed from the Benjamin Sheares Bridge, and to keep permissible distance for weaving from/to ECP/Ford Road IC. Since the restriction of land usage is not so severe, a few alternatives can also be considered. The followings would be the 3 alternatives for the comparison study. (Refer to Table 9.6)

Alternative I concentrates on the main traffic flow and the area of land is extremely small. But a loop ramp is necessary and thus the design speed has to be reduced to 40 km/h and the horizontal curve radius would be hardly maintained at 60m. Alternative II is to connect ECP and KLE by a loop ramp with large curve radius to maintain the design speed at 50 km/h. The necessary distance for deceleration is sufficiently maintained. Alternative III is to reduce the possibility of driver's misjudgment. The connecting ramps are reduced to the necessary ones to increase the smooth traffic flow.

As shown in Table 9.6, the alternative I is selected as the most suitable one. In the case of this alternative, the distance with Ford Road is maintained at 450m and the traveling speed in the weaving section at 40 km/h. In terms of traffic management, alternative II is ideal but taking into the consideration of Singapore practice which is to use the least amount of area to obtain the maximum effect, the alternative I which can reduce the area by 3.5ha, is the best.

#### 2) KLE/Nicoll IC and PIE/KLE/PYE IC

Since this interchange was located near the congested intersection of Nicoll Highway (Guillemard Rd.) and Mountbatten Rd., the connections from those ones to the north bound of KLE were required so as to eliminate the congestion.

Between KLE/Nicoll IC and MRT there are one way traffic roads ; those are Sims Av. and Geylang Rd.. There is a need of connections of KLE with these roads based on the future traffic demand. Since the distance in between all those connections were so small, the Nicoll Highway IC and KLE/PYE/PIE IC had to be studied as in one.

Table 9.6 Evaluation of KLE/ECP IC

| Alternative | I | II | III |
|---|---|---|---|
| IC Type | Modified Trumpet Type | Modified Y-Type | Modified Trumpet Type |
| Service Direction | Full service except from Marina East to Changi direction of ECP. | Full service except Marina East to Changi direction of ECP. | Full service except Marina East to Changi direction of ECP. |
| Design Speed | V = 40 km/h | V = 50 km/h<br>From ECP to Marina East : V = 40 km/h | V = 50 km/h<br>From ECP to Marina Center to Marina East: V = 40 km/h<br>From ECP Changi to KLE: V = 40 km/h |
| Minimum Radius | R = 50 m | R = 90 m<br>( V = 40km/h, R = 50m ) | R = 110 m<br>( V = 40km/h, R = 50m ) |
| ROW Area | 7.6 ha | 11.1 ha | 9.1 ha |
| Traffic Safety | As from KLE to ECP Changi bound is ri-ght diverging and from KLE to Marina East is left diverging, driver will be bewil-dered. | As from KLE to ECP Changi bound is righ-t diverging and from KLE to Marina East is left diverging, driver will be bewil-dered. | No problem. |
| Structure | Structure length is long by many ramps.<br>Configuration is simple.<br>Probable for future alteration. | Configuration is complicated.<br>Not easy to alter the structures. | Configuration is simple.<br>Nos. of ramps is the least. Possible for future alterlation |
| Evaluation | ROW Area is the smallest among the three Traffic safety is better than Alt.-II.<br>◎ | ROW Area is the largest among the three.<br>○ | Weaving length is the shortest from the Fort Road IC.<br>Lowest service.<br>Traffic safety is the best.<br>○ |

The distance between noses for succeeding merging, succeeding diverging and weaving is to be desirably more than 300m according to the Japanese standards.

The priority of ramp connection was studied by taking into consideration the amount of traffic demand and the existence of diversion route. Fig. 9.6 shows the portion of the Nicoll IC, surrounding expressway interchange and service traffic. Fig. 9.7 shows the future traffic volume (year 2010, AM peak and PM peak). The summary is shown in the table from 9.7 to 9.9. As to the diversion of routes, there found good accesses from/to the PIE/Paya Lebar Rd. IC and the ECP/Fort Rd. IC and no connections were necessary to Guillemard Rd.. The priority of ramps were found to be the connection with the city bound of Nicoll Highway, the off ramp of east bound on Sims Av., the off ramp of the west bound on Geylang Rd. and then on and off ramps of Mountbatten Rd..

Consequently the desired connections for each road and each direction are as follows :

- *Nicoll Highway : city bound direction*
  In order to reduce the load to the existing junction with Mountbatten Rd., this road should be connected towards PIE east and west directions and PYE.

- Mountbatten Road : ECP direction
  Since the ECP/Fort Road IC is nearby, necessity of the connection other than Jurong direction is low.

- Sims Avenue
  The necessity of connection towards PYE is the highest. If KLE/PYE/PIE IC is geometrically complicated, the connection other than that should be given up.

- Geylang Road
  The same condition as Sims Avenue.

From the viewpoint of convenience for road user, it is better to give connecting service as much as possible. To reduce the load on the existing junction of Nicoll and Mountbatten, it is desired to have an entrance and exit from Sims or Geylang Road.

Two points were considered. One was to provide as many access as possible and the other was to reduce traffic towards already congested junction of Nicoll and Mountbatten Rd.. The configuration of the interchange was studied for two alternatives as shown in Table 9.10. One was to allow more weaving hence making the configuration simpler as one and the other was to reduce weaving. During the study, some facilities were considered as control points, such as the private land in between the KLE and Guillemard Rd., the junction and school on Mountbatten Rd. before the ECP, the mid-rise flats and private houses before the PIE, the noses of the PIE/Woodsville IC, the nose of the PIE/Aljunied Rd. IC, and the viaduct and road surface at the MRT. The alternative allowing weaving was simple enough in structure however, there considered disadvantages such as more possibility of accidents and slower traveling speed of approximately 30km/h. Eventually the alternative allowing no weaving was recommended.

Among those two alternatives, there were differences for the KLE/PYE/PIE

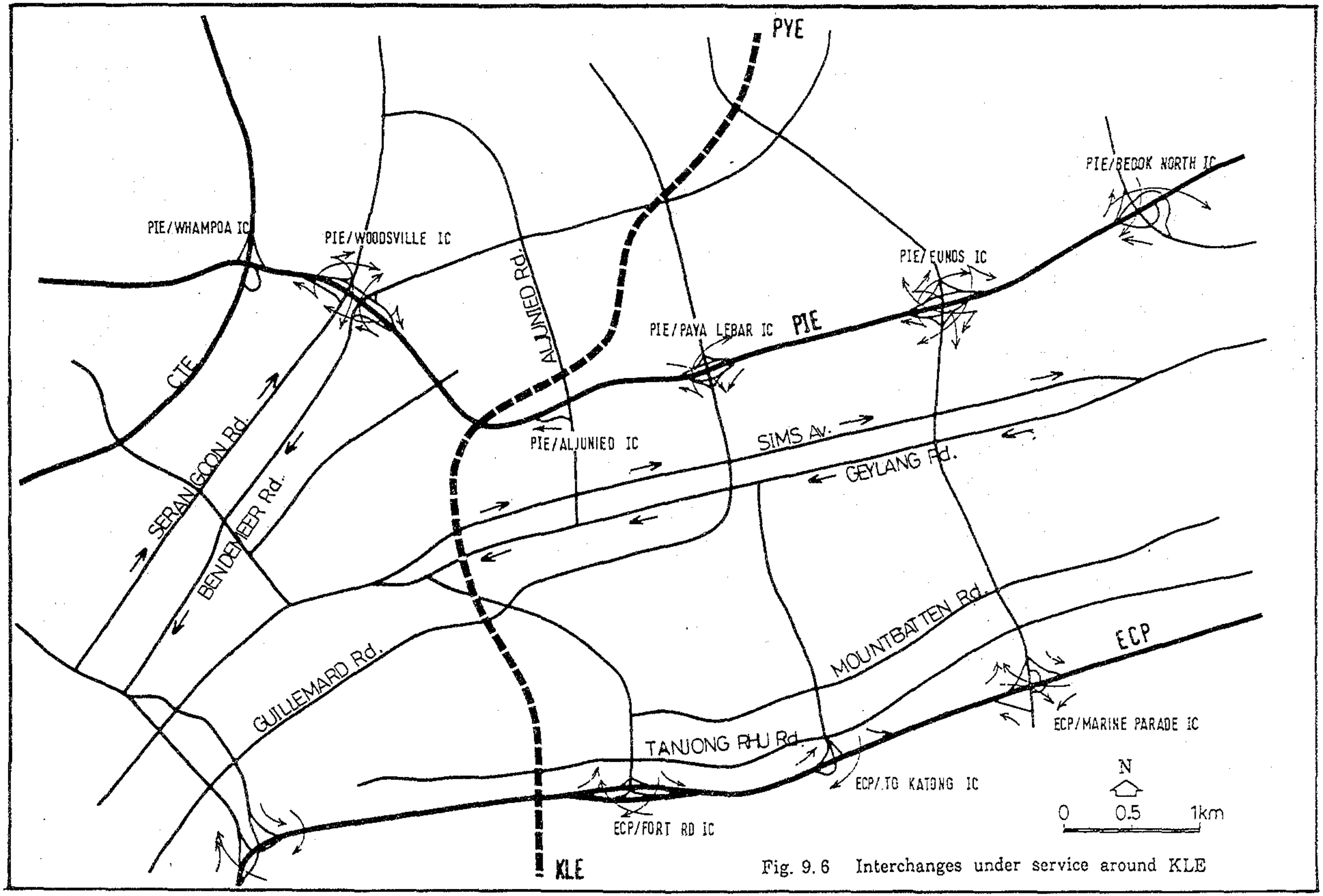



Fig. 9.6 Interchanges under service around KLE

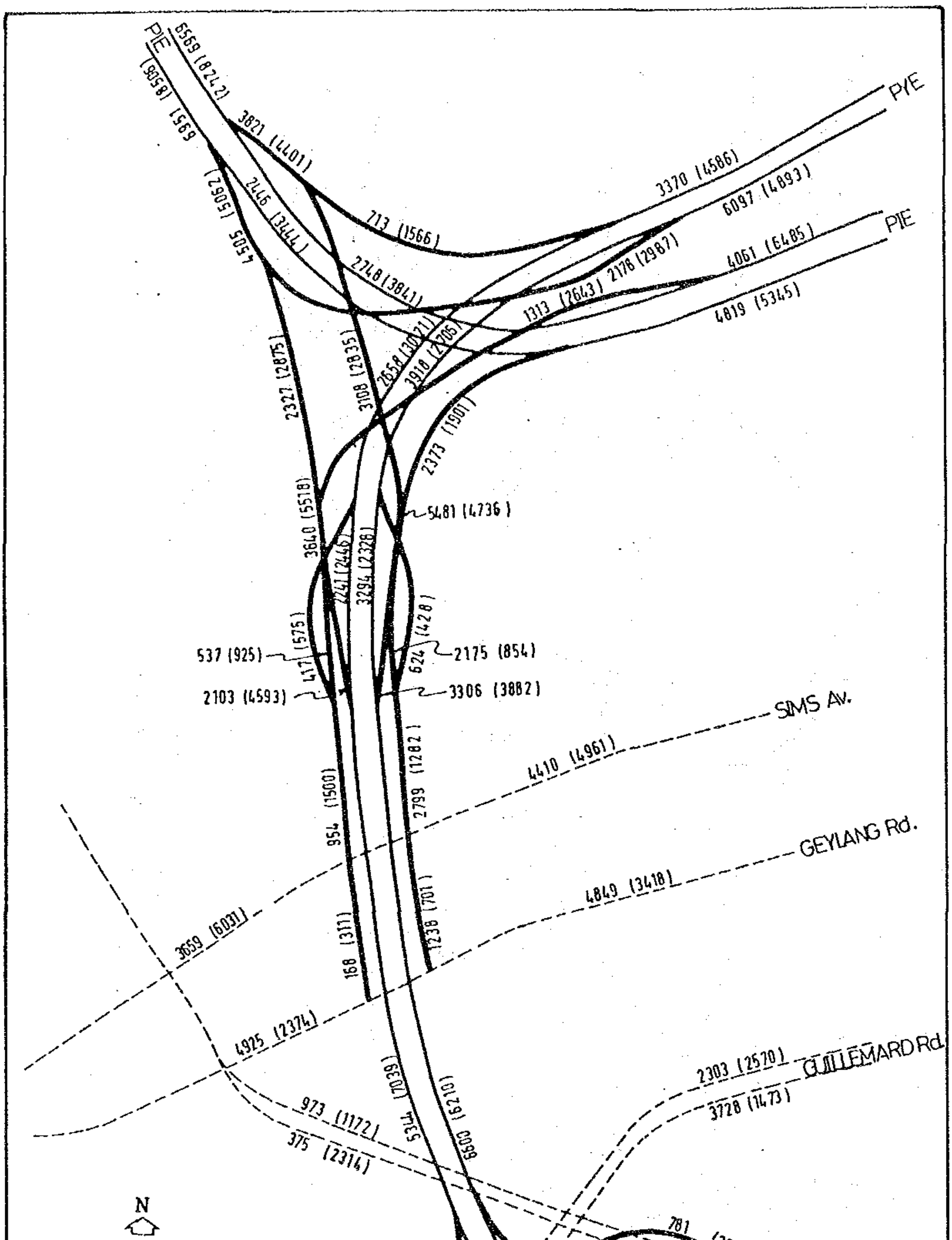



Fig. 9.7 Traffic volume on Nicoll IC & KLE/PYE/PIE IC

Table 9.7 Necessity of connection (road network)

Off-ramp

| | PIE-W | PYE | PIE-E |
|---|---|---|---|
| Sims-East | ◎ | ◎ | ○ |
| Geylang-West | ○ | ◎ | ○ |
| Nicoll-West | ◎ | ◎ | ○ |
| Mt.batten-S | ○ | ○ | ○ |

On-ramp

| | PIE-W | PYE | PIE-E |
|---|---|---|---|
| Geylang-East | ○ | ◎ | ○ |
| Sims-West | ○ | ◎ | ○ |
| Nicoll-West | ◎ | ○ | ○ |
| Mt.batten-S | ◎ | ○ | ○ |

Table 9.8 Necessity of connection (traffic demand)

Off-ramp

| | PIE-W | | | PYE | | | PIE-E | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mark | AM | PM | Mark | AM | PM | Mark | AM | PM |
| Sims-East | ○ | 573 | 272 | ○ | 312 | 214 | ○ | 515 | 156 |
| Geylang-West | ○ | 573 | .272 | ○ | 312 | 214 | ○ | 515 | 156 |
| Nicoll-West | ◎ | 558 | 699 | ◎ | 414 | 751 | ◎ | 1183 | 226 |
| Mt.batten-South | ○ | 319 | 123 | △ | 175 | 97 | △ | 287 | 70 |

On-ramp

| | PIE-W | | | PYE | | | PIE-E | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mark | AM | PM | Mark | AM | PM | Mark | AM | PM |
| Sims-East | ○ | 154 | 300 | ○ | 209 | 288 | △ | 115 | 164 |
| Geylang-West | ○ | 154 | 300 | ○ | 209 | 288 | △ | 115 | 164 |
| Nicoll-West | ○ | 234 | 570 | ◎ | 471 | 921 | ◎ | 728 | 1765 |
| Mt.batten-South | △ | 27 | 53 | △ | 37 | 51 | △ | 20 | 29 |

Table 9.9 Priority of construction of ramps

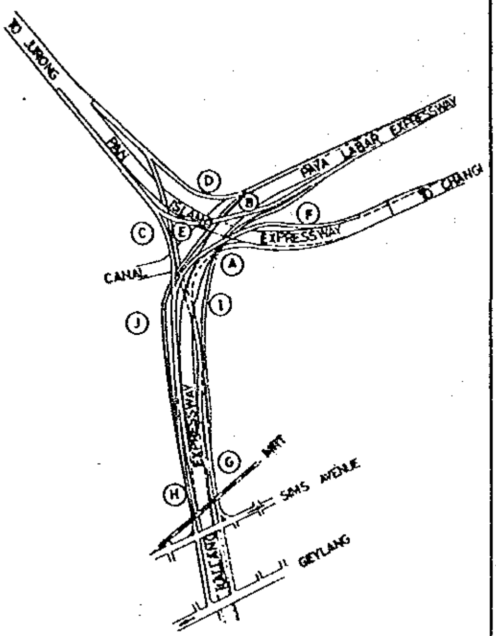
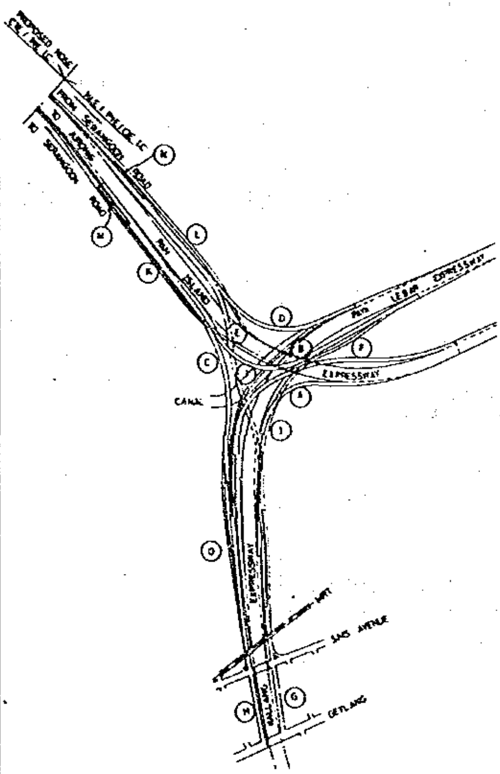
Off-ramp

| | PIE-W | PYE | PIE-E |
|---|---|---|---|
| Sims-East | ◎ | ◎ | ○ |
| Geylang-West | ○ | ◎ | ○ |
| Nicoll-West | ◎ | ◎ | ◎ |
| Mt.batten-S | ○ | △ | △ |

On-ramp

| | PIE-W | PYE | PIE-E |
|---|---|---|---|
| Geylang-East | ○ | ◎ | △ |
| Sims-West | ○ | ◎ | △ |
| Nicoll-West | ◎ | ○ | ◎ |
| Mt.batten-S | ○ | △ | △ |

## Table 9.10 Evaluation of interchange at KLE/PYE/PIE IC

| I T E M | | Alternative allowing weaving (Route-I) | Alternative avoiding weaving (Route-I) |
|---|---|---|---|
| General Plan | |  |  |
| Align-ment | Horizon-tal | All ramps have design speed of 60km/h. Curved alignment with radius of 130m at 3 points. Complicated curved stretch is counted a few in general view. | To meet design speed of 60km/h, horizontal alignment with curves of more than 130m radius is applied. Ramps connecting KLE & PIE Changi bound bend acute. |
| | Vertical | C,F-ramps at three tier & E-ramp under-passing KLE take slope of nearly 5%. Other ramps take comparatively moderate vertical slopes less than 3%. | B,F-ramps at three tier & ramps joining them take slope of nearly 5%. At many points of merging & diverging, gradient difference between ramp is more than 5% |
| Traffic Congestion and Traffic Safety | | Access form is simple. Drivers rarely lose directions. Weaving on ramps take place at 4 points. KLE north bound and south bound yield traveling speed of 35 km/h because of short weaving length as 320m & 270m respectively. On north bound, climbing slope of 5% make weaving with high speed vehicle(80km/h) difficult. Merging & diverging on throughway take place at 4 points, but at 2 points inter-nose distance acquire only 60m on ramps where merging & diverging repeat due to enough weaving length attained. | Since Woodsville IC is near to the next , weaving on ramps each other remain to both directions. Weaving length is attained 215m for west bound of PIE 295m for KLE & PYE from PIE west. Repetition of merging & diverging with throughway take place once on west bound of PIE & once on south bound of KLE. Inter-nose distance on rampway stretch is attained sufficient except for 1 point of 150m. |
| Comparison | | Unsatisfiable. | Satisfiable. |

IC at the formation height of connecting ramps from Sims Av. and Geylang Rd. as well as those due to the restrictions to cross the MRT (either the interval of piers for the tunnel alternative or the head room clearance over MRT for the viaduct one).

The geometric standard was satisfied though, there would continue highly dangerous sections which were caused by very tight horizontal and vertical alignment and very closely adjoining zones of diverging, merging and weaving.

The distance between the existing Aljunied ON ramp and the proposed off ramp towards KLE can be only kept to be about 160 m after construction of KLE/PYE/PIE IC. THis section will have weaving phenomenon, and therefore, the probability of traffic accidents and traffic congestion would be undoubtedly high. The Study Team proposed to close the existing ON ramp because of the reason mentioned above. However, the other neighbouring PIE interchange or proposed PYE/Paya Lebar IC will function as a substitute interchange.

### 9.3.3 PYE

Base on the Phase I study of the traffic demand, the Alternative Route-I plans to have PYE/Paya Lebar Rd. IC, PYE/Airport Rd. IC, PYE/Tampines Rd. IC, PYE/Punggol IC and the PYE/TPE IC. Alternative Route-II to have PYE/Paya Lebar Rd. IC, PYE/Tampines Rd. IC, PYE/Punggol IC and the PYE/TPE IC. Alternative Route-III will add PYE/Defu Av. IC to Route-II. Since location of Route-II is changed from Defu Av. area to the green belt at the outskirts of the Air Base, a reconsideration of the interchanges is to be made.

Along the PYE, the developed Hougang New Town exists and also 4 new towns are in the planning stage. The new towns are all located at the northern side of Tampines Road. Since almost all the PYE user would be using PYE/Punggol IC and PYE/TPE IC, whichever the alternative would be, the conditions are same and there is no need for changes. On one hand for the existing Hougang New Town access, in case of Route-I & II, PYE/Paya Lebar Rd. IC or PYE/Tampines Rd. IC can be used. If it is Route-III, the access convenience from Defu Av. IC will be very bad. (Refer to Fig.9.8). Judging from the size of the Hougang New Town, there is a need to give an easy access.

As Route-I is passing through the Air Base, the new town is connected only to PYE/ Paya Lebar Rd. IC and PYE/Tampines Rd. IC. As to routes-II and III, if connected to Hougang Ave 3 then it is possible to service into the city using PYE and KLE. Near the SBS bus depot the connection interchange between Hougang Av. 3 and PYE towards the city would be constructed. In combination to this the Route-III PYE/Defu Rd. IC will be removed.

These interchange plans are summarized in Table 9.11 and the outline of each interchange plan is described as below.

**1) PYE/Paya Lebar Rd. IC (Route-I, II and III)**

This interchange is the key interchange in the PYE. This interchange shall serve for trips to KLE, PIE, TPE. Whichever the direction is traffic volume would be heavy. It would be used as an important distributor type interchange.

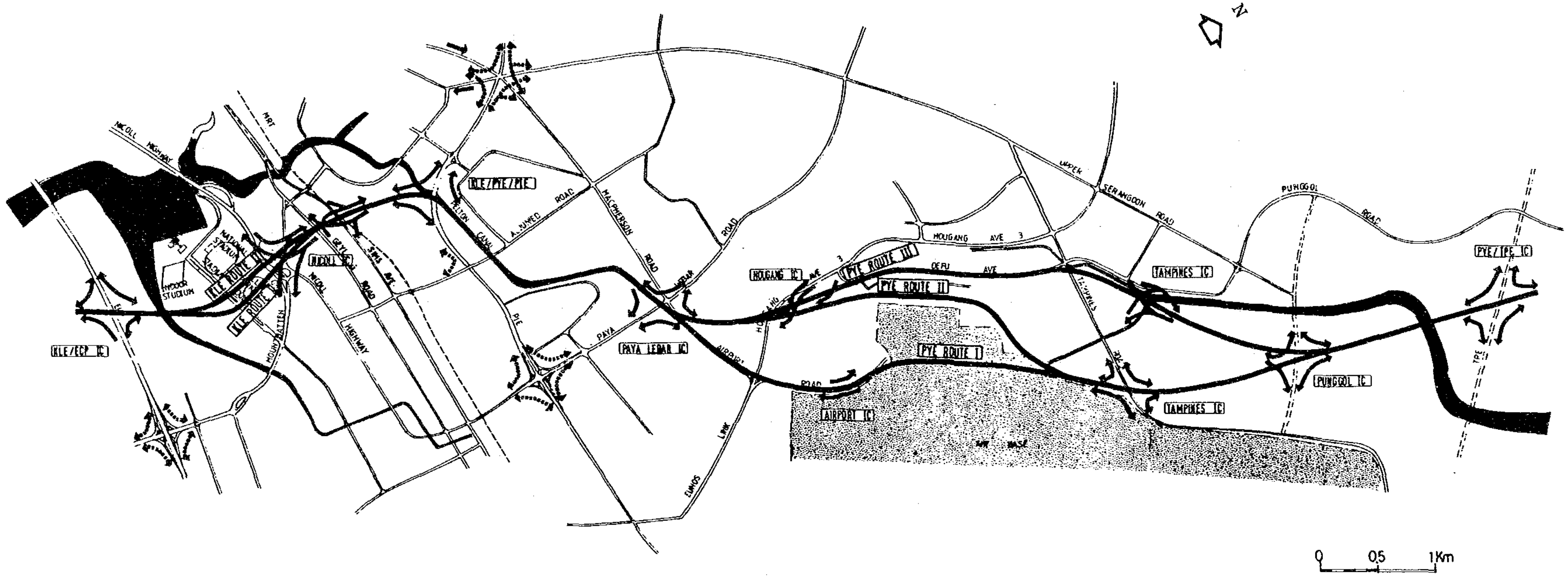
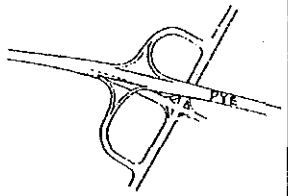
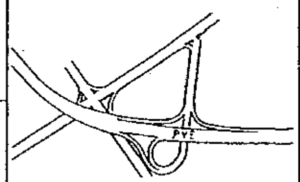
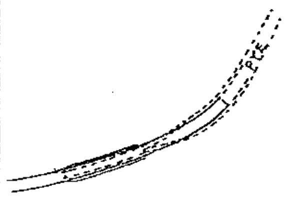
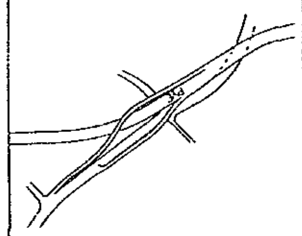
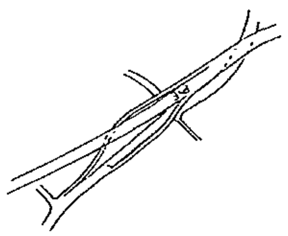
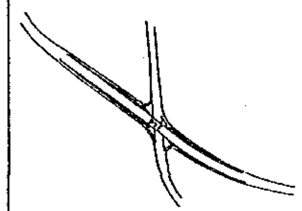
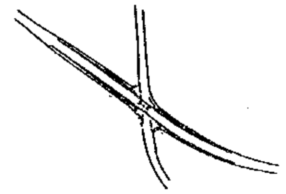
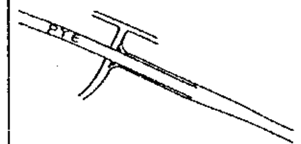
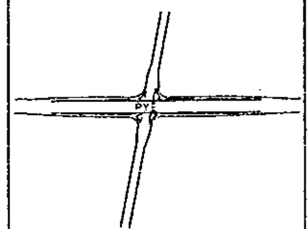
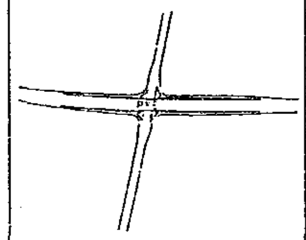
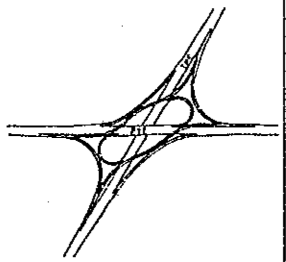



Fig. 9.8 Interchange locations & service direction of KLE & PYE

THE FEASIBILITY STUDY OF SELECTED EXPRESSWAYS IN SINGAPORE

## Table 9.11 Outline of IC's PYE

| IC Name | Route | Sketch | IC Type | Design Speed (km/hr) | Alignment: Minimum Radius (m) | Alignment: Maximum Gradient (%) | Length Structure: Viaduct (m) | Length Structure: Tunnel (m) | Traffic | Land: Area (ha) | Land: Land Use |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PYE/ Paya Lebar Road IC | I |  | Partial Clover leaf | 40 | 80 | 5.98 | 900 | - | -Design speed of slip ramps are 40km/hr.<br>-Using minimum radius of 45m for Route- I and Route II.<br>-The 2nd IC is nearby existing intersection.<br>-The 2nd IC is a signalised intersection. | 8.5 | Industry |
| | II |  | Trumpet B Type | 40 | 45 | 5.93 | 950 | - | | 5.7 | |
| | III | | | 40 | 45 | 5.86 | 950 | - | | 5.7 | |
| PYE/ Airport Road IC | I |  | Half Diamond | 50 | 300 | 5.00 | - | 800 | -The IC is in the tunnel | 0.8 | Industry |
| PYE/ Hougang Avenue 3 IC | II |  | Half Diamond | 50 | 150 | 4.50 | 900 | - | -Diverging and merging noses are nearby existing intersection. | 2.0 | Industry Special use |
| | III |  | | 50 | 150 | 5.10 | 500 | - | | 1.2 | |

| IC Name | Route | Sketch | IC Type | Design Speed (km/hr) | Alignment: Minimum Radius (m) | Alignment: Maximum Gradient (%) | Length Structure: Viaduct (m) | Length Structure: Tunnel (m) | Traffic | Land: Area (ha) | Land: Land Use |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PYE/ Tampines Road IC | I |  | Diamond | 50 | 1200 | 1.41 | - | - | -The 2nd IC is a signalised intersection. | 3.5 | Industry |
| | II |  | | 50 | 1200 | 1.41 | - | - | | 3.5 | |
| | III |  | Half Diamond | 50 | 150 | 4.08 | 400 | - | | 0.4 | |
| PYE/ Punggol IC | I & II |  | Diamond | 50 | 2000 | 3.84 | 1300 | - | -The 2nd IC is a signalised intersection. | 1.5 | Industry Residence |
| | III |  | | 50 | 1200 | 3.84 | 1300 | - | | 1.5 | |
| PYE/ TPE IC | I, II & III |  | Modified Clover leaf | 50 (loop ramp 40) | 60 | 5.00 | 2000 | - | | 16.0 | Agriculture |

The interchange is designed in a location that main throughway is to pass through above the intersection of Paya Lebar Rd. and Airport Road. The usable land is restricted to the northern side of Paya Lebar Road. Therefore depending on the route there are different ramp structure. Alternative Route-I (Air Base route) is to use above the Airport Road that makes a splitting incomplete clover type interchange. Route-II and III has a concentrated trumpet B type of interchange.

In Route-I, there is no loop ramp and the minimum curve radius of 80m is maintained; therefore there is no geometrical problem. But near the existing signalized intersection, 2 new signalized intersections would be sited 250m apart.

As for the Route-II and III, based on the conditions of the available land and the distance for weaving and intersections, a trumpet B type with maximum curve radius of 45m is recommended. These two alternative routes can only be separated by 200m from the existing traffic signal.

Three proposed interchanges have about 6% of maximum longitudinal gradient. The length of viaduct section is about 900m and the land area needed is about the same at 3.0 ha.

**2) PYE/Airport Rd. IC (Route-I)**

This interchange was located at Airport Rd. where the PYE transited from viaduct to tunnel and served only towards the direction of TPE. The vicinity of this interchange is used as Kim Chuan sewerage treatment plant on the west side and the Air Base facilities on the east. Therefore a large scale interchange facility would be very difficult.

A diamond type was recommended to avoid the facilities mentioned above and to use minimum space. Since the merging and diverging zones would be in the tunnel and the connection with Airport Rd. was a center ramp type, there remained problem of traffic safety.

**3) PYE/Hougang Avenue IC (Route-II and III)**

This interchange was recommended to make a pair with the PYE/Tampines Rd. IC for servicing the traffic demand of Hougang area, and to be a half diamond type. The selected location was for both the Route-II and III near the intersection of Hougang Av. and Defu Av.. At this intersection the SBS bus depot and Civil Defense were considered to be the control points. As for the Route-II Defu Av. was recommended to be repositioned nearer to the main through road to avoid three tier structure.

**4) PYE/Tampines Rd. IC (Route-I, II and III)**

The location of this interchange of the Route-I and II is the western side of the Air Base crossing Tampines Road and of Route-III is an extension of newly constructed road connected to Hougang Ave. 7 in future. The interchanges of Route-I to III would be diamond or half diamond type interchange. The design speed is maintained at 50km/h and the maximum longitudinal gradient used is 1.5%.

In the case of Route-I and II, a diamond type is recommended considering the future traffic demand, distance from the existing intersection, land area required and the underground water pipeline.

There were 2 other alternatives to connect with Hougang Av. 7 or with Tampines Rd. for the Route-III to have a better access to Hougang New Town. But in the former case, the problem is direct noise towards the medium rise apartment. In the latter case, there is difficulty of traffic regulation of the nearby existing junction. The former described newly constructed road connection has been decided.

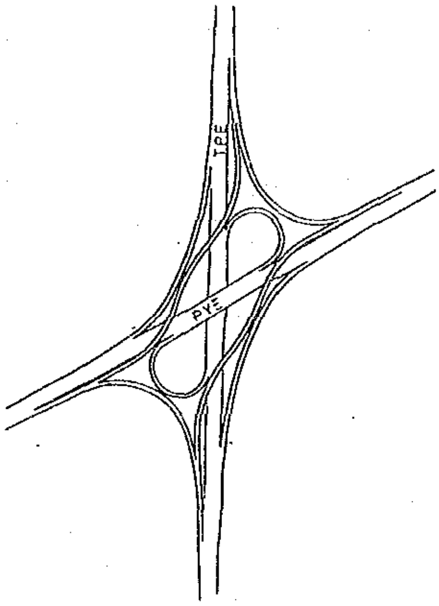
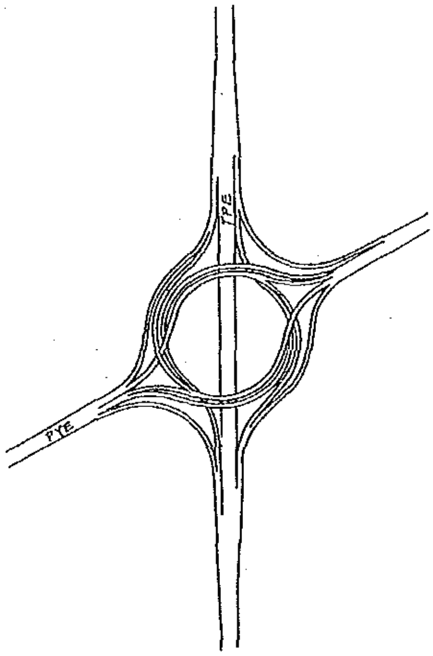
**5) PYE/Punggol IC (Route-I, II and III)**

This interchange was recommended to have services with the planned road from the future Kangkar New-town. The area near this location is programmed to be used as agriculture and industry in future. The interchange was recommended to use a diamond type taking into consideration the access with nearby areas, land for the interchange (for rational use of land) and traffic management. The land required for this was approximately 1.5ha.

**6) PYE/TPE IC (Route-I, II and III)**

For this interchange there were two types studied which were clover and turbine as shown in Table 9.12. Both types were designed as servicing full directions and satisfying the design speed of 60km/h except at loop sections. The land used for both types were same 16ha though the turbine one was superior in traffic wise since it could secure the minimum radius of 130m. The clover type was recommended at the end because of the reasons such as; the total length of structure being 1,000m; better adaptability in structure alteration; and more possibility in reduction of land. The capacity of all ramps was approximately 1,200 vehicles per peak hour which should be enough in traffic management.

Table 9.12 Comparison of PYE/TPE IC

| Alternative | Alternative I | Alternative II |
|---|---|---|
| IC Type | Modified clover-leaf type | Turbine-type |
| Sketch |  |  |
| Service | Full Service | Full Service |
| Design Speed | V = 60 km/h<br>(Loop Ramp V = 40 km/h) | V = 60 km/h |
| Minimum Radius | R = 60 m | R = 130 m |
| Arrea | 16 ha | 16 ha |
| Traffic Performance | - Loop ramp joining expressways reduce traveling speed.<br>- Merging & diverging to throughway at 3 points disturb traffic flow on throughway. | - Merging & diverging to throughway at 2 points disturb traffic flow on throughway. |
| Structure | - Viaduct is 2000m long.<br>- Configuration is simple. Reformable in future. | - Viaduct is 3000m long.<br>- Configuration is complicated. Not reformed in future. |
| Evaluation | - Traffic performance is inferior to Alternative II.<br>- ROW can be compressed. ◎ | - Traffic performance is superior to Alternative I.<br>- IC characteristics can not allow ROW compress. ○ |

## 9.4 Soil and Materials

### 9.4.1 Geological Profile of Singapore Island

The topography of Singapore is summarized that the main island is 42km from east to west , 22km from north to south with the area of 584 km2. The highest altitude is 166m at Bukit Timah Hill  and the highest building is 280m tall. Thus the island has moderate terrain profile.

The geology of Singapore Island is classified into 4 regions (See Fig.9.9).

- From the center to the northern coast is  distributed a granite rock stratum called Bukit Timah Granite.
- From the western to  the south western coast is distributed sedimental rock strata called Jurong Formation.
- In the north  eastern part is distributed diluvial strata called Old  Alluvium.
- In the south eastern pastern part is  distributed alluvial strata called by Kallang Formation.

The geological characteristics of the strata relating to the Study Route are described hereafter.

#### 1) *Bukit Timah Granite*

This stratum is continued from the Malay Peninsular and consists of granite and weathered layer. Near Mandai Hill fresh  granite is used as good aggregate material. This stratum is ordinarily weathered from the surface to the depth of 20m to 30m and granulated into sandy clay mixed with gravel.

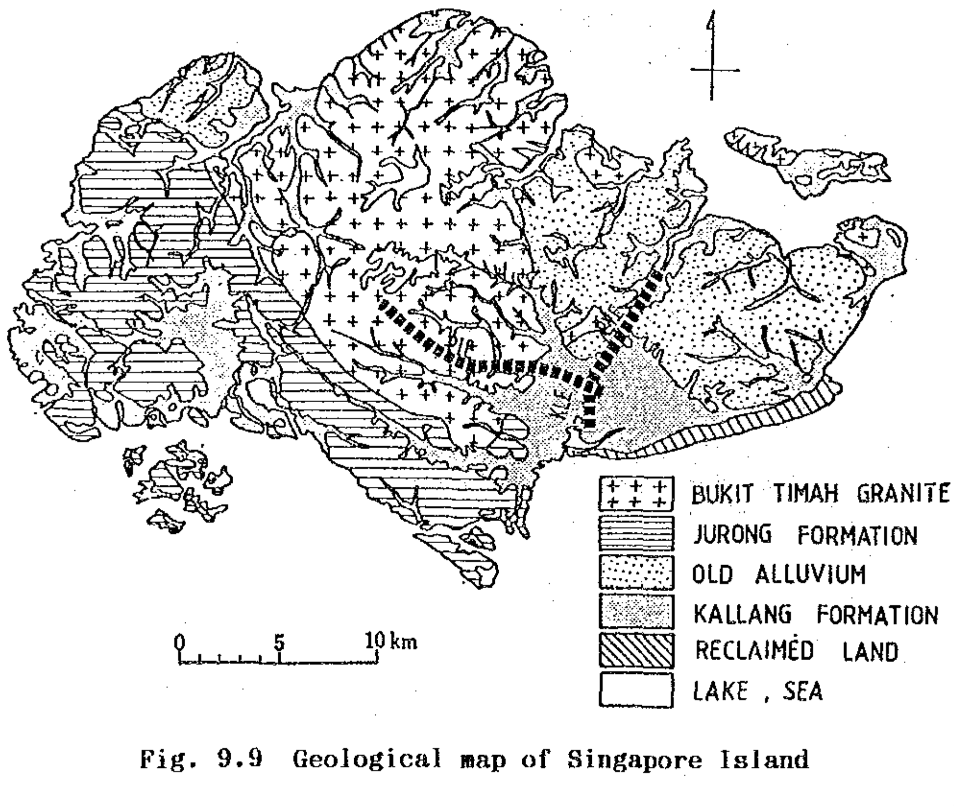



Fig. 9.9 Geological map of Singapore Island

**2) Jurong Formation**

This strata consists of such sedimental rocks as conglomerate, sandstone, mudstone, shale, tuff and its weathered layer. The distribution is from Jurong district to the city area. The thickness is from several centimeters to several metres. The strata folds complicated even with vertical stratification. There is a difference in the rock quality and its strength various. Together with the large inclination, the depth of bed rock suddenly changes in depth. Conglomerate and sandstone are relatively slow in weathering speed, on the other hand mudstone, shale and tuff have been weathered to low strength.

**3) Old Alluvium**

This strata consist of alternation of such layer as gravel, sand and clay and distribute all over north eastern region including Katong and Changi district. The soil is firm as to yield the blow numbers of the standard penetration test 20 to 50 times for sand and 10 to 20 times for clay. In general the gradation is good and used as filling material for reclaiming the Changi Airport, Marina South and the off-shore Tanjong Rhu. This strata have estimated depth of 100m approximately.

**4) Kallang Formation**

This formation is widely located at the city eastern region. Since alluvial deposits are all classified into this strata, it can be esteemed as covering all over island. At the nearby shore it include much of marine clay, although inland area as riverside and marshy places include black peat and loose sand layer. Thickness is 5 to 10m inland and maximum 40m on shore. Marine clay of the Kallang Formation is the typical and problematic clay with soft and high compressibility popularly found in South East Asian countries as listed in Table 9.13.

**Table 9.13 Soil property of alluvial strata**

| | Upper Clay | Lower Clay |
|---|---|---|
| Natural moisture (%) | 60-80 | 50-60 |
| Specific gravity | 2.60-2.75 | 2.60-2.72 |
| Bulk density (tf/m3) | 1.49-1.65 | 1.65-1.84 |
| Liquid limit (%) | 80-95 | 60-80 |
| Plastic index (%) | 50-65 | 35-50 |
| Undrained shear strength (tf/m2) | 1.0-3.0 | 4.0-7.0 |
| Over consolidation ratio | 1-2 | 1-2 |
| Compression coefficient | 0.7-1.3 | 0.5-1.0 |
| Sensitivity ratio | 5-10 | 6-12 |

Source: Japan Association of Soil Mechanics and Foundation Engineering

## 9.4.2 Geological Condition along Alternative Route

**1) PIE**

Based on the soil survey results executed by PWD (April-August 1990), the geological condition is estimated. This survey covers the locations from Thomson IC to Kim Keat as shown in Appendix 9.2. This stretch falls in the Bukit Timah Granite area. The weathered depth and surface deposits were unknown factors. The result of the survey reveals the following;

- The surface deposits include humus soil and marine clay.
- Weathered granite is 20m to 40m deep.
- Jurong Formation (weathered sedimentary rock) penetrates between surface layer and the weathered granite.

The surface layer is thicker than expected and is found to include considerably soft soil. It is noted that a deep fundamental structure is needed. Nearby the stretch it can be estimated the presence of the boundary of the Bukit Timah Granite and Jurong Formation. In Jurong Formation the strata inclination would change suddenly. Piled foundation of point bearing would be difficult to construct.

Fig. 9.10 shows the conceptual profile of the site.

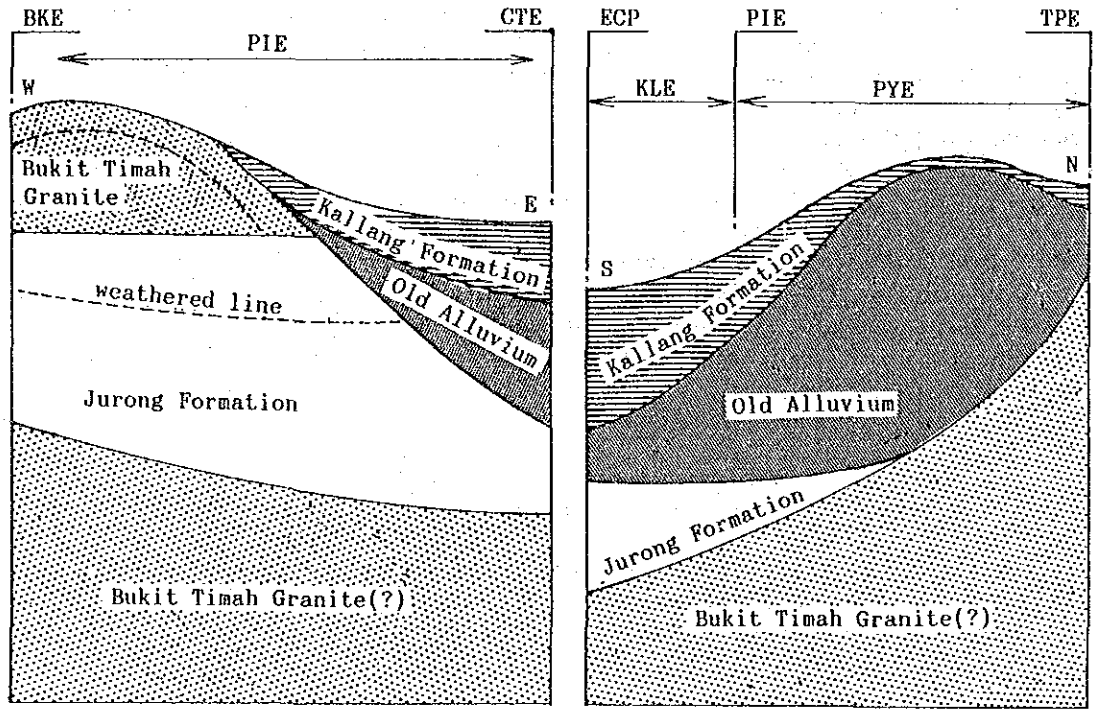



**Fig. 9.10 Conceptual profile of the site geology**

2) KLE

The sources for estimation of geological profile are as follows,

- Survey on 1979 of Singapore eastern coast reclamation works.
- Survey of the National Stadium Sports Complex works.
- Boring logs along the Pelton Canal supplied by the PWD.

The Kallang Formation is the marine clay layer sedimented on the aluvial deposit formed by eroding the Old Alluvium. Since the surface of the eroded Old Alluvium is in depth changing from 20m to 50m on shore, the thickness of overlying marine clay changes remarkable. This sea formed clay layer is deposited in sea level as thin layer of hard clay.

Marine clay layer is divided by firm clay film into upper marine clay and lower marine clay. Both are very soft layer. Nearby Kallang Park, the 2 boring logs implies the presence of the Old Alluvium at the depth of 15m to 17m, although this does not mean the horizontal elevation of Old Alluvium. Nearby Pelton Canal, some boring logs indicate the Old Alluvium 10m to 15m deep except 25m deep at one point.

3) PYE

The area along the Pelton Canal and northward until Paya Lebar Road has the similar geology as on the KLE. The Kallang Formation becomes thin and instead the Old Alluvium goes up to the ground. After crossing Paya Lebar Road, the Old Alluvium becomes predominant. From here until the northern part to the Tampines IC, data of the local soil condition is not available. Therefore the geological condition is estimated based on the field survey conducted by the Study Team.

The ground of Air Base is formed by the Old Alluvium as a good diluvial strata. Toward the west is a marshy basin of the Serangoon River with fish farming ponds remaining outside. At present, the area is used as the dumping area of reclaimed land. Near the river mouth, hardened reddish and yellow gray soil is observed. Above this layer, sedimentation of humus and dark gray soft clay is observed. The aluvial deposit is considered to be not so deep as the Kallang Formation. The dark gray clay seems marine clay. Yellow gray soil is considered as the weathered layer of Bukit Timah Granite. Near the basin it is possible the Old Alluvium had been eroded out. From the above observation, the thickness of the alluvial sediment is estimated less than 10m.

### 9.4.3 Subgrade for Roadway and Foundation of Bridge and Viaduct

The locations where ground level expressways are planned require attention to the subgrade strength. On these reclaimed land in depth of 13m to 15m, subgrade borrow material should be carefully placed.

Piled foundation in medium size is suitable for bridge and viaduct. Since the marine clay of the Kallang Formation can not be expected to have sufficient bearing strength, the Old Alluvium 20m to 50m deep would be selected as bearing strata. In the Kallang Formation belt, although a thick soft clay layer remains, it is not necessary to consider the negative friction to the pile design because no settlement occurred in the surrounding area.

### 9.4.4 Selection of Construction Materials

Subbase material quarried from the Jurong Formation give more than 40% of CBR Value. Subgrade material is specified more than 5% of CBR Value by PWD. Weathered granite and Old Alluvium are considered to meet this requirement. Materials for construction work are almost available except for cement and steel.

## 9.5 Hydrological Conditions

Since the land area of Singapore is small and surrounded by the sea, the river length is short and scale of discharge is small. Rivers and canals are fully furnished so as to lessen the hazard of flood. The highest elevation of the land is only 166m and the terrain is relatively flat. Therefore the tidal level is influential. The high water level is regulated based on the statistical record of high tidal level for the rivers in Singapore.

### 9.5.1 Design Rainfall Intensity

In Singapore a local downpour is often encountered and governs the design rainfall intensity as shown in Appendix 9.3. Providing duration of rainfall corresponding to return period, rainfall intensity is given in the specified nomograph. Probabilistic rainfall intensity with the return period of 5 year is applied for the design of drainage facility as shown in Table 9.14.

**Table 9.14 Design intensity of rainfall**

| Duration of Rainfall | Intensity of Rainfall of 5-year Recurrence Interval |
|---|---|
| 5 | 220 |
| 10 | 170 |
| 20 | 135 |
| 30 | 110 |

Rainfall duration is essential for the planning of surface drainage. In Singapore the time of rainfall duration is applied from 5 minutes to 30 minutes depending on the catch basin area, the topographical condition and the drainage type.

### 9.5.2 Hydrological Condition of Relevant Rivers

The main rivers flowing in the Study area are the Geylang River crossing to the KLE, the Serangoon River and Pelton Canal crossing to the PYE. High water level of Geylang River is at 101.75m RL, Serangoon River at 102.05m RL. Design high water level shall be 0.75m above the tidal high water level. High water level of Pelton Canal is 101.75m RL because regarded as along the southern coast of Singapore Island.

### 9.5.3 Hydraulic Condition of Drainage Facility

The mean flow velocity and discharge of side ditch, pipe culvert and box culvert shall be derived from the Manning Formula. The mean flow velocity shall satisfy the following requirements,

- For concrete made side ditch shall be more than 1m/second and less than 3m/second.

- For earth work side ditch such as dug out and grass covered shall be less than 1.5m/second.
- Allowance of 20% to the calculated cross sectional area shall be added.
- Free board shall be 15% to the required depth.

### 9.5.4 Drainage Planning for Underground Facility

The drainage facility of depressed stretch shall be referred to the Conditions for use of Pumped Drainage Systems for Basement Underground Facilities in the provision of Surface Water Drainage Regulations specified in Singapore Code of Practice 3. Herewith described are the points of the provision,

- The capacity of drainage pump to be installed shall satisfy the rainfall of more than 150 mm/hour.
- Drainage duct to be equipped shall be capable to discharge the rainfall with the duration time more than 3 hours as shown in Table 9.15.

**Table 9.15 Relationship between duration and rainfall**

| Duration(hr) | 3 | 4 | 5 | 6 | 12 | 24 |
|---|---|---|---|---|---|---|
| Rainfall(mm) | 151.4 | 210.6 | 253.4 | 281.9 | 376.7 | 533.2 |

## 9.6 Preliminary Design of Structures

### 9.6.1 Widening of PIE Interchange Structure

**1) Eng Neo Interchange**

The existing expressway at the Eng Neo IC is straight. As the widening plan requires additional one lane at at-grade section, the bridge at the PIE/Eng Neo IC is recommended to be widened to have one additional lane and approach ramp by adding pretensioned PC simple girder. The joint should be fixed by cast-in-situ concrete to secure traveling comfortableness and safety though, the concrete beam should be left for approximately six months to wait for settlement of deformation after production prior to erection so that the secondary stress on the existing girder could be minimized.

**2) Adam Interchange**

As the horizontal alignment near the Adam IC is good and there is not much leeway on both sides of the existing expressway. The PIE could be used as 8 lane by reducing the width of median strip and hard shoulder. Box culverts should be added behind of abutment on both sides for one lane on ramp. The formation level of ramps were lowered to make space for the construction of box culverts. The Adam Rd. surface should be covered by temporary decks to pass existing number of lanes while constructing box culverts.

**3) Mt. Pleasant Interchange**

Widening the existing expressway from 6 to 8 lanes is not possible under the present IC bridge due to restricted width. The east bound main road was recommended to be newly constructed for four lane behind of existing interchange north abutment. Since the construction would be right behind of abutment and also Mt. Pleasant Rd. requested full lane service, a PC hollow slab structure was adopted. Foundation piles and abutment should be constructed under full face temporary decks to secure enough service during construction. The piles should be constructed by a reverse circulation method under head room clearance restriction.

**4) Thomson Interchange**

At the north of existing 14 span continuous PC girder bridge, new east bound four lane expressway and two lane ramp viaducts were recommended. The new bridge should be pretensioned PC girder with supporting two piers cross-head type sub-structure to satisfy aesthetics. The point of crossing over Thomson Road should be composed of post-tensioned PC girder to overcome long span problem. The configuration of girders and piers should be made the same as existing ones to improve aesthetics consideration. During the transfer of loop ramps, the traffic from Thomson Road to the east bound of PIE should be diverted to right turn by signals. (refer to Fig. 9.11 and Appendix 9.4)

**5) Toa Payoh Interchange**

Both the on ramp and off ramp of the Toa Payoh Interchange bridge are commonly used by Jurong-bound traffic. To reduce the load on very congested Toa Payoh roundabout, the off ramp will be shifted to Kim Keat so that only the on ramp will remain at the Toa Payoh Interchange

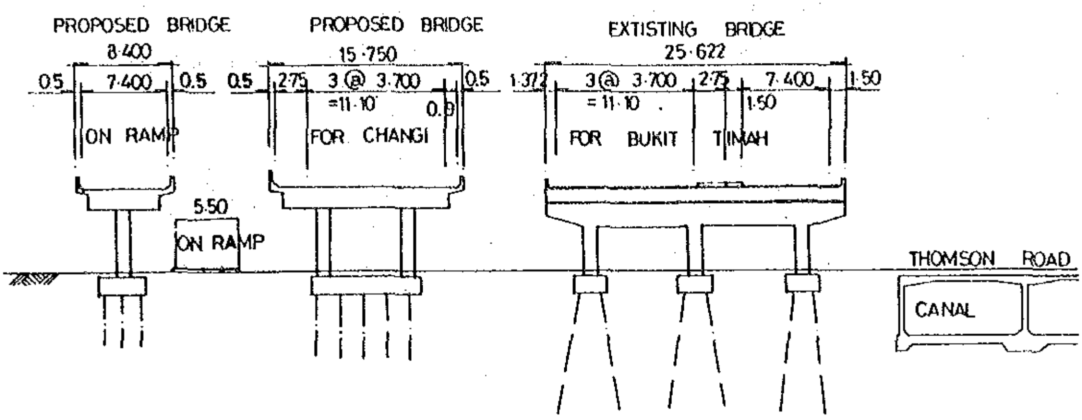



**Fig. 9.11 PIE Thomson IC : Widening plan by viaduct works**

bridge. Since the present level of service should be retained, the new bridge should be constructed outside of existing one prior to removing it. For over-bridge on the PIE, the new bridge should be PC precast girder with a support at the median strip. The new off ramp at the PIE/Kim Keat IC should be completed prior to demolishing the one at the PIE/Toa Payoh IC. (refer to Appendix 9.5)

The following are points to note in the planning of this bridge.

- The MRT crosses the PIE diagonally right on the eastern side of the bridge. If the off ramp bridge were built here, a span of 80m or more would be required. Considering the difficulty in approaching the PIE, it is advisable for the on ramp to be moved to Kim Keat.

- To cross the PIE with 1 span, the span would have to be 57m. The girder height would also have to be higher and the proposed height would also be higher. As this would cause difficulty in approaching from the existing road, pier will be located in the median strip of the PIE and the crossing done by 2 spans.

**6) Kim Keat Interchange**

The purpose of moving the Jurong-bound off ramp at the Toa Payoh Interchange to this interchange is to avoid construction hampered by severe restrictions. It is also to avoid the load on the extremely congested Toa Payoh roundabout. Since the new bridge would cross over the PIE diagonally by a curve, it should be a two span PC precast girder with a support at the median strip.
The sub-structure should be a cross head type. The on ramp from the CTE should use a new slab over the canal. The function of the canal should be retained by erecting the structures outside of it. (refer to Fig.9.12 and Appendix 9.5)

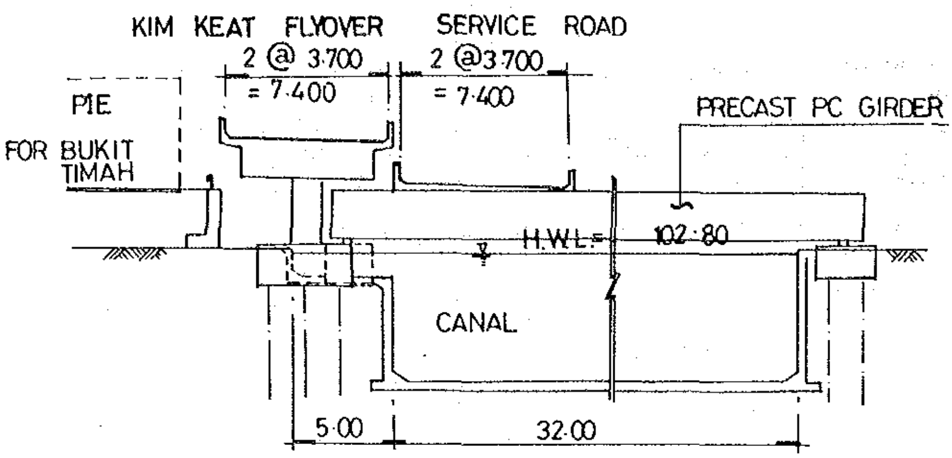



Fig. 9.12 PIE Kim Keat IC : Widening plan by raising & bridge works

### 9.6.2 Structures on KLE & PYE

**1) Standard viaduct type**

(1) Span length

Span length is influenced by the crossing configuration with road and river; land use situation; soil condition; nearby environ; economics, aesthetics and constructions. As determination of the span length is heavily influenced by the superstructure type and economics, careful attention must be paid to these factors.

a) Optimal span length of standard viaduct structures

PC precast beams are generally simple structures with a maximum usable span of 50m. However, for reasons of transportation, workability and economics, precast beams of around 30-35m are often used. In this study, economics and aesthetical will be examined to determine the optimal span length.(refer to Appendix 9.6)

Evaluation of aesthetics hinges heavily with the evaluator and hence cannot be done objectively. In this study, the evaluation is based on the relationship between the ratios of the dimensions of the span length, vertical clearance and depth of the superstructure The following can be said.

- In the case of a continuous viaduct, from the relationship between the depth of the superstructure and the span length, the feeling of thickness can be determined from just the thickness of the superstructure. Therefore, for shorter spans, the beam decreases in height and becomes more slender.

- From the relationship between the vertical clearance and span length, the elevation difference of 10m to 25m between ground level and the proposed height matches the economic span length. The span length which suits the proposed height is 30m to 35m.

- If the relationship (h/H) where h (h) is the depth of superstructure and (H) the vertical clearance; is below 0.4, the structure will not give a feeling of being overpowered. If the elevation difference between ground level and the proposed height is taken to be between 10 to 12.5m, a span of 30m or less is desired.

- *Summarizing the above evaluations, a span length of 30m is most* aesthetically appealing. However, as the surrounding view, balance, etc of the environment where the viaduct is to be sited are also important aesthetical factors, they will each be examined in separate sections.

In conclusion, the optimal span length as determined by integrating both economics and aesthetics is as stated in Table 9.16. Perspective view of suitable span length with 30m for standard viaduct is shown in Fig 9.13.

**Table 9.16 Suitable span length for standard viaduct**

| | Span Length (m) | | | |
|---|---|---|---|---|
| | 20 | 25 | 30 | 35 |
| Economics | * | * | * | |
| Aesthetics | | | * | |
| Past experience | | | * | * |
| Evaluation | | | * | |

*b) Span length of the crossing*

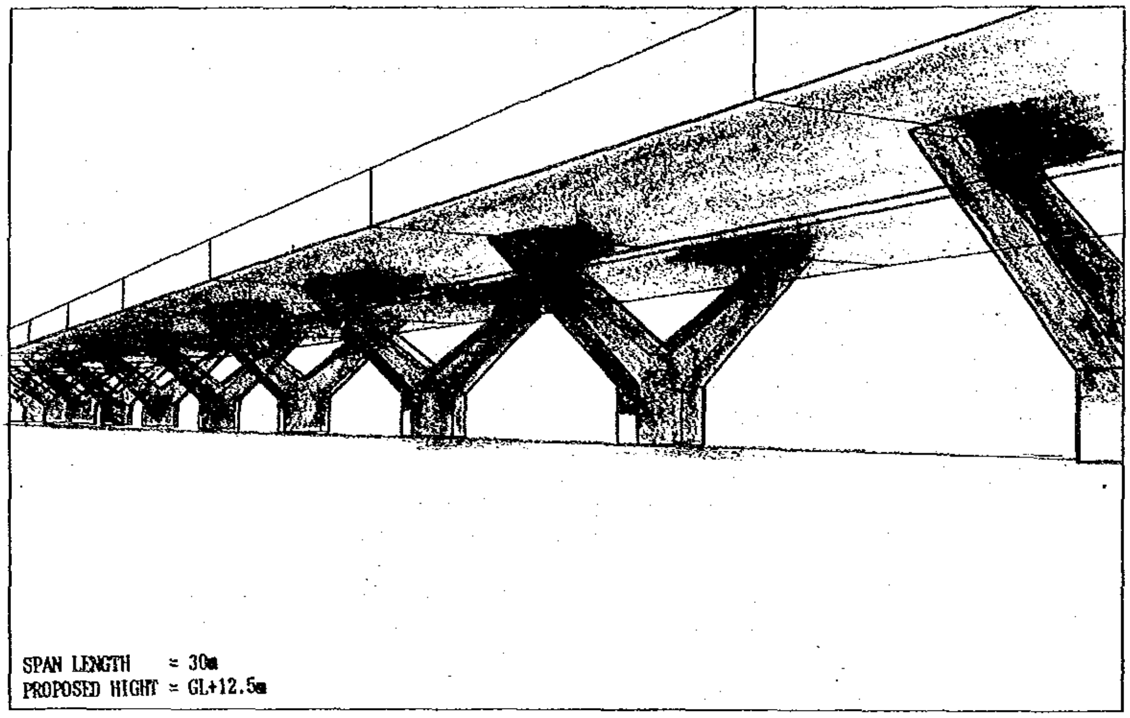
The proposed expressway crosses a number of roads, rivers, etc. and there are places where the standard span length cannot be used. For these places, the following methods will be applied.

- When the center to center length of piers are less than 45m then PC precast girders with long cross head support should be used.

- When the center to center length of piers are more than 50m then the cast in-situ three span continuous girder should be used. (refer to Table 9.17).

**Table 9.17 Span length of continuous girder** Unit : meter

| | Side Span | Center Span | Side Span | Bridge Length |
|---|---|---|---|---|
| TYPE 1 | 35 | 50 | 35 | 120 |
| TYPE 2 | 35 | 55 | 35 | 125 |
| TYPE 3 | 40 | 60 | 40 | 140 |
| TYPE 4 | 45 | 70 | 45 | 160 |
| TYPE 5 | 50 | 80 | 50 | 180 |



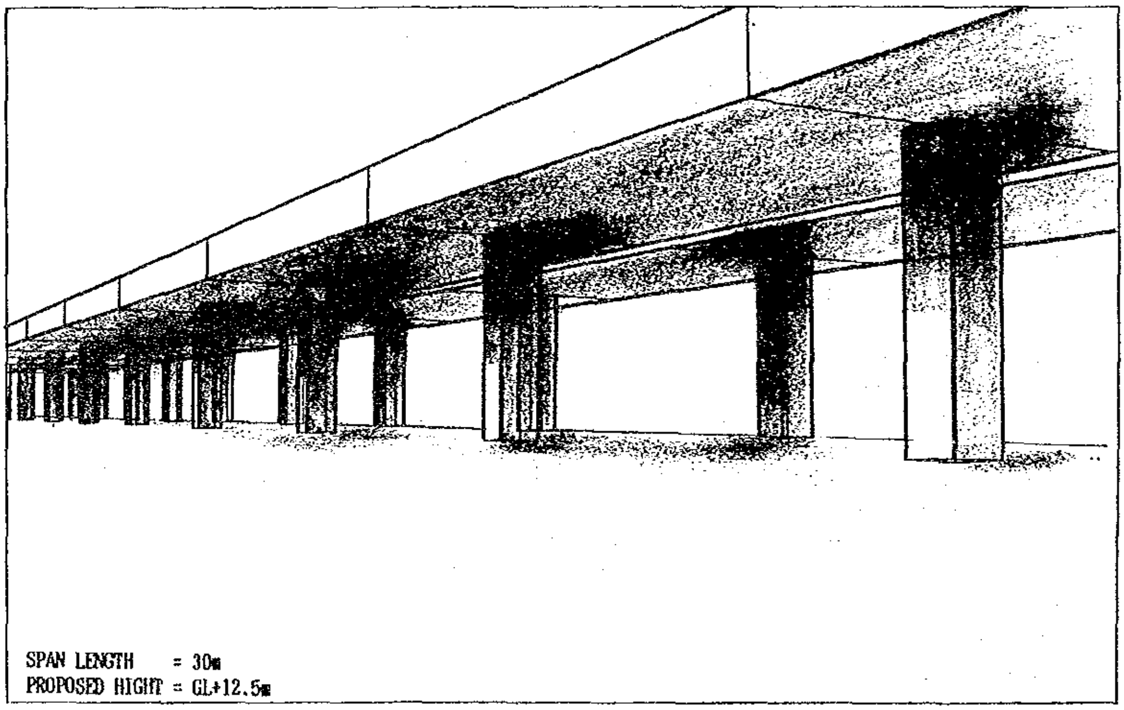




Fig. 9.13 Standard viaduct type with span 30m long

(2) Selection of girder type for standard viaduct

The Study Team had adopted precast prestressed concrete girder for the superstructure of standard viaduct with span of 30m long as optimum for economics and aesthetics.

TYPE 1: T section beam
TYPE 1: T section beam
TYPE 2: I section beam
TYPE 3: U section beam

These types are characterized as described in Table 9.18. Each type has its limitation on application.

Three types have some individual characteristics and selection of suitable girder type is dependent on the site condition. The Study Team will recommend I-beam, because I-beam is the most economical type and easy for erection, and slab deck can easily follow the twists of bridge surface. The last reason is very influential to the selection of girder type.

**Table 9.18 Characteristics of precast prestressed concrete girder**

| | Advantage | Disadvantage | Problem or Merit |
|---|---|---|---|
| T | Period for slab deck casting is short. Beam depth is the thinnest among all types. | Slab deck can not easily follow the twisted surface of bridge. Construction cost is transverse tendon needed in the slab deck. | Expensive. Many twists of bridge surface encountered in KLE and |
| I | Even in case of excessive twist of bridge surface, slab deck can easily follow the twisted surface. lowest, because slab deck need not transverse tendon and crane in ordinary scale for erection can be used. As beam weight is light, transportation and erection are easy. | Slab deck work takes longer time than T-beam. Beam depth is thicker This type needs strutting support for stability during erection setting. | Economical. Easy handling. Adaptable to the twists of bridge |
| U | As numbers of beam is less than the other types the period of fabrication and Transportation can be reduced.Sectional stability can keep self-support during erection. | Slab deck can not easily follow the twisted surface of bridge. As beam weight is heavy, large trailer and crane are needed for erection. Transportation and erection are not easy. | Many twists of bridge surface encountered in KLE and PYE. |

**(3) Selection of pier types**

For KLE and PYE viaducts, piers are often seen more closely by pedestrians and drivers than the beams. Therefore, the shape of pier become especially important from an aesthetical point of view. For studying pier types, various factors were taken into consideration such as functions, construction, economy, maintenance and aesthetics.

a) Aesthetics

i) Shape of pier
The material of superstructure is concrete. As it supports a relatively heavy load and as the effects of earthquakes can be discounted, concrete which is very strong against compression is used. Due to the nature of concrete, concrete piers can come in various cross sectional shapes such as rectangles and round shapes as well as various pier shapes such as Y-shapes. As for this viaduct, considering the width of superstructure and effective land usage and other factors, Y-shaped pier and multi-pier are adopted.

ii) Cross section shape
Many types of cross section shapes of piers include rectangle, polygon and wall types. In view of stress, rectangle section is better than round section. As for the horizontal alignment , in places where pier has to be located inside canals, a round cross section will reduce resistance to water flow.

iii) Structure of pier
In view of aesthetics, fewer piers are desirable as it allows more space below the beam and better lighting. However, the number, location and shape of pier are also determined by other conditions including soil condition, shape of the superstructure, width and load. A study was made into the structure of pier considering aesthetical continuity with pier on both sides while taking these conditions into account. The results are as follows.(refer to Appendix 9.6)

- Y-shaped pier is visually rhythmic while multi-type is eye-catching. Clearly, Y-shaped pier is superior in this aspect.
- When the difference between ground level and the proposed height is 7.5m or less, the vertical part of the pier is hidden in the ground and is visually unappealing. It is desirable for Y-shaped piers to have at least 10m of elevation difference.
- In places where roads run parallel below the viaduct (Defu Avenue and Airport Road on the PYE), using 2-pier type will structurally require the roads to pass between the piers. Drivers will consequently receive a feeling of being overpowered.

iv) Fitting pier and beams
The relationship between the superstructure and the supporting pier is an important point in the structure of the bridge. As simple PC precast beams have been chosen for the superstructure in this study, it is not possible to support directly with pier. But using cross-head structures, sight of horizontal member can be minimized.

b) Structure aspect
Y-shaped pier is possible for a 6 lane viaduct. A multi-pier type is used for 8 lane viaduct.

c) Economic aspect
Multi-pier type on the standard section is 5% more economical than Y-shaped pier. Over Pelton Canal, three pier type is clearly more economical than Y-shaped pier. The difference in cost is as much as 38%.

d) Others
In case where a road runs parallel beneath the viaduct, by locating the Y-shaped pier in the central median then the expressway can be separate into two sides. The wider divider also improves traffic safety as well as traffic flow.

e) Conclusion
Multi-type pier and Y-shaped pier have their own respective characteristics. The decision on which one to use cannot be applied to all cases as there are local conditions such as route alignment, soil condition and surrounding environment to be considered. Each route will

**(4) Selection of foundation**

The soil condition is not good along the whole stretch of KLE and the southern part of PYE. A foundation with deep bearing will be necessary. A piled foundation is recommended. Reviewing the construction record of the site, driven PC square pile and H-section steel pile are generally used.

Design horizontal forces are vehicle traction and wind loading. Hence the horizontal design force does not generally require pile. Considering these conditions, the selection of the pile type can be based on the weight of the superstructure and the thickness of the soft soil layer. For heavy structures like the Geylang River Bridge, cast in situ concrete piles are suitable.

For viaducts in the north where the bearing strata lies less than 20m deep, PC piles are to be used. In the south bearing strata is deeper and H-section steel piles can be used.

The area to the north of the Tampines Road has revealed the Old Alluvium as the bearing strata less than 10m deep. For viaduct works which are expected in the vicinity of town area, cast in situ concrete pile will be used. For heavy structures like bridge, a caisson foundation is recommended for economy.

**2) Tunnel planning**

Tunnel stretches are proposed as 500m long in the Route-I Alternative of the KLE and 1350m long in the Route-I Alternative of the PYE. Following items have been clarified in the tunnel planning.

- Selection of tunneling method,
- Shape and dimensions of tunnel cross section,
- Location of portal,
- Treatment of underground ducts and neighboring construction,
- Ventilation facility, its flow system and capacity,
- Emergency facilities.

**(1) Selection of tunneling method and tunnel cross section**

Applicable type of tunneling method shall be selected on the comprehensive appreciation of geology, location, depth of proposed elevation, highway geometry, and economy. Geological condition along the KLE may impose some difficulty on the tunneling in Kallang Park due to soft marine clay, however free-conditioned location and economics motivate a use of box shaped cross-sectional tunnel by cut and cover method. A rectangular cross section is the most effective shape to a multi-lane carriageway with sign boards. In general cut and cover method tends to yield settlement caused by lowering water table and heaving at excavation. In the Project area soil stabilization, recharge method or other particular coffering should be used based on the soil exploration. Even on the stretch in the common tunnel section the sheathing requires sheet piles with large bending inertia for the depth. On the tunneling in Kallang Park it necessitates coffering of larger scale supposedly such as column wall or diaphragm wall in RC. Traffic service at important crossings with tunneling work can be attained by covering plate. (refer to Appendix 9.7)

**(2) Treatment of underground duct and neighboring construction**

Drain ditch out of various underground facilities involves some difficulty to diverge with the result of temporary support. In neighboring construction adjacent to important structure, coffering is recommended to apply the diaphragm wall method in touch with side walls.

**(3) Location of portal**

In determining the location of portal, attention is paid to avoiding *curving alignment stretch and large gradient profile as to appear* suddenly outside the portal. Drivers who come out from inside tunnel are dazzled by the light and not ready to operate a sudden steering. This will result in an accident. These problematic points are encountered at portals on both tunnels of KLE and PYE that are positioned in a curve with 400m radius and in the S shaped curve with 500m radius. In order to make up for this defect, lighting at portal and sight line induction utility are necessary.

**(4) Ventilation facility, its flow system and capacity**

Facility planning of ventilation system shall consider tunnel length, longitudinal gradient, traffic volume, natural wind velocity, percent of trucks and allowable exhaust gas concentration. Necessity of mechanical ventilation can be preliminarily decided on the basis that the product of tunnel length(km) and traffic volume(vehicle/hour) exceeds 2000 in the case of carriageway with one way two lanes. Since the Kallang Park Tunnel yields 4000 and the Air Base Tunnel yields 10000 roughly, both tunnels require mechanical ventilation.

Air flow system and capacity are main planning subjects. Ventilation capacity is predominantly governed by traveling speed. The capacity corresponding to the slower traveling speed near to traffic congestion would be costly in association with the initial cost and maintenance cost increasing. The fundamental conditions for ventilation capacity has been proposed by Permanent International Association of Road Congress (PIARC), where the vehicle traveling speed of 10 km/hour is reasonable and recommendable. The other fundamental conditions the Team employed are a heavy vehicle ratio of 15% and a traffic volume per lane of 2120 vehicles per hour.

Longitudinal flow system is recommendable because of its tunnel length and economics. Since the tunnel length is short, natural ventilation effect and traffic ventilation effect can be efficiently utilized.

Although a longitudinal flow system is not suitable for furnishing with a smoke extraction apparatus, this apparatus should be laid out as a part of emergency facility aside the ventilation system by considering the present state of the art. Jet fans can be suspended and installed at the ceiling in the common space with traffic signs under the ceiling. No additional space for jet fans requires tunnel inner section.

**(5) Lighting facility**

The tunnel alignment in curved stretch requires the continuous induction of sight line around portal. The lighting system shall gradually change the luminance from the entrance to the inside to avoid black hole phenomena.

**(6) Emergency facilities**

Emergency facility plays a serious role in tunnel to make use of closed space. As in the ventilation planning, emergency facility planning also can be decided on the basis of tunnel length and traffic volume. Principal facilities to be equipped are listed in the followings. Facilities which need structural accommodations are a shaft of smoke extraction, evacuation tunnel or drift, water supply, and drainage pumping facility.

- Emergency warning facility to serve detecting fire and accident, reporting to fire station and police, warning to drivers.

- Fire fighting facility to consist of fire extinguishers which are portable and capable of initial extinguishing, fire hose and hydrant.

- Evacuation facility to assist drivers who abandoned vehicle and evacuate on foot safely in the evacuation gallery and tunnel guided with directional signs and a smoke extraction apparatus.

- Hydrants to serve fire fighting by fireman equipped at both entrances and evacuation drift.

- Monitoring facility to serve traffic control in ordinary and communications and monitoring of evacuation and fire fighting in an emergency by means of independent television cameras installed at an interval of 200m.

- Drainage pumping facility to pump out water.

**3) Structure planning of retaining wall and trough structure**

In the Study of KLE and PYE, approaching roadway stretch will be recommended to be constructed by retaining wall type or trough structure type for the economical land use. Types of retaining wall have been listed up in the order of economy as the followings,

Type-1. Stone masonry wall,

Type-2. Block masonry wall,
Type-3. Gravity concrete retaining wall,
Type-4. Inverted T shaped retaining wall,
Type-5. U shaped retaining wall,
Type-6. Concrete skin wall anchored by strip.

Since KLE and PYE are to be high grade expressway and in need of economical land use, Type-1 and 2 are not suitable. Type-3 and 6 do not suit to such a soft ground as KLE route where most of the retaining wall stretch locates. Selection shall be made among Type-4 and 5.

Various versions for Type-4 and 5 is shown in Appendix 9.8. Five versions are described as below,

**Type-A** is applicable to the embankment approach to bridges,

**Type-B** is applicable to depressed stretch and to the tunnel approach and is the most economical type in case of firm subsoil,

**Type-C** is a modified Type-B for use in soft subsoil. Since the cost will be more than twice of Type-B. Complicated construction procedure is disadvantageous.

**Type-D** is applicable to the tunnel approach in case of soft subsoil. This type has such characteristics as simple construction and smooth road surface free from subsoil settlement. The cost will be twice of Type-B. Buoyancy uplifting is counted by thicken slab under ground water.

**Type-E** is for semi-covered highway stretch with cantilever slab at the top of wall for rationale land use. Structural stability requires trough type in U shaped cross section. The additional loading on the cantilever slab makes wall thicker than the Type-D.

Since the maintenance fee is favoured and operating performance of expressway should be up-held, Type-D as U shaped trough is recommendable.

Retaining wall stretch in the KLE includes retained embankment approach approximately 200m long; U shaped trough approximately 400m long; and semi-covered trough approximately 800m. Expressway stretches assigned to U shaped trough have a steep gradient nearly of 3% and partly a curved alignment encountered as in the sloping stretch from Geylang Bridge to entrance of Tunnel under Kallang Park and as in the stretch from below the MRT Viaduct to northward. In these stretches, traveling forces from vehicle onto road surface are impact-associating and heavier than standard sections. Roadway stretches in question require high durability and pavement structure with sound subgrade. Repair works are difficult at those places.

**4) Structures of interchange**

The design requirement of interchange structures are the followings;

- Not allowed is such a scale of structure as to require expansion of the land take.
- Not to obstruct the sightline of traveling vehicles.
- Able to comply with change in carriageway width and gradient