(6) Alternative C–N

This route diverges from Alternative A–1–N at about 500 meters south of Chan Road, then bends to the northeast to traverse highly developed commercial and residential areas, crossing Sathon, Silom and Rama IV Roads with affecting embassy, cemetery and multi-storied buildings. It joins Alternative A–1–N behind Bangkok Railway Station.

This route must pass through highly developed commercial and residential areas to avoid the large scale cemetery area which comprises two large cemeteries, two temples and four private schools and these spread over about 0.5 square kilometers.

The adoption of this alternative would entail serious problem of the demolition of Embassy of Laos, small scale cemetery and a number of multistoried buildings. Therefore, this alternative was rejected from the further comparative study due to the reasons mentioned above.

(7) Alternative D–N

This route is the same as Alternative A–1–N up to Bangkok Railway Station, where it bends to run northwards along the railway line, and merges Alternative A–1–N in the vicinity of the Bang Sue junction of the southern railway line.

More than a half of its entire length of the route runs along the railway line and intended to use the ROW of SRT. However, this alternative has the serious problems that :

- The alignment must pass too close to the Royal Palace;
- The Expressway must flyover the existing very important Chitlada Station for the Royal train; and
- Very expensive disposition is anticipated to provide the interchange and on or off ramps because of very poor accessibility (i.e. elevated railway is planned above the existing at-grade double tracks).

Therefore, a further route study for a comparison was not done due to the inferiority of the above route location conditions.

8.5.3 East Route

Eight (8) shortlisted alternative routes were taken into consideration to select an optimum route (see Fig. 8–2, Table 8–2 and Appendix Table 8–1).

(1) Alternative A–1–E

This route starts from Rama VI Road and runs along Khlong Sam Sen towards the east, passing the point about 250 meters north of the Victory Monument on Phahol Yothin Road and then passes over Din Daeng Road to join FES at a swamp area behind the Makkasan Railway Station.

After the Station it continues to run eastwards partially along a road planned by BMA and passes through the crossing point of Khlong Sam Sen and Phra Khanong-Bang Kapi Road, and joins the route established by DOH which partially runs along the railway line in Hua Mak. This route terminates beyond the National Road No. 3344 at the connecting point with the DOH road which runs towards the planned new airport.

This route passes parallel to the Khlong Sam Sen on its northern side for about 3 kilometers where residential houses and other buildings are densely built-up. But this strip is less congested and less modernized compared with the cases of other alternative routes.

It must be noted that for the preservation of the environment of the Victory Monument, which is regarded as one of the nation's most important historical features, the adoption of the undercrossing scheme at Phahol Yothin Road was requested by the Thai Coordination Subcommittee Members.

Less difficulties are found in the Expressway planning in the middle stretch of this alternative route, since the alignment passes though open areas and the subcorridor of BMA's road.

In the eastern-most stretch of this alternative, the route has to traverse housing complex area for about 1.5 kilometers. The alignment is determined so as to be elevated above the proposed at-grade road which is planned by the DOH.

When looking into the route selection in the East corridor from the view point of the practical interchange planning, this alternative is expected to provide the best dispositions.

The planning of double Y–type interchange between the First Stage Expressway System (i.e. Din Daeng-Port Section) is possible utilizing the swamp area behind Makkasan Railway Station. Furthermore, this alternative route also provides an appropriate land space to plan a Y–type interchange between the N–S Route since proposed interchange location is found to be less densely developed and no serious control point is observed.

No adverse effect to the traffic flow during the period of construction, because the route does not follow the existing congested street or road.

(2) Alternative A–2–E

This route starts from the same point of the Rama VI Road as Alternative A–1–E and runs towards the east, passing at the point about 500 metres away from the Victory Monument on the Phahol Yothin Road, and joins with the Alternative A–1–E at Din Daeng which is located behind the Makkasan swamp area.

This alternative provides a modified alignment at the western end of the Alternative A–1–E to avoid a proximity to the Victory Monument. However, the alteration of the alignment of the Alternative A–2–E will entail the following disadvantages :

- Violation of military area;
- Demolition of the housing area of the police department; and
- Increase of the length of the Expressway.

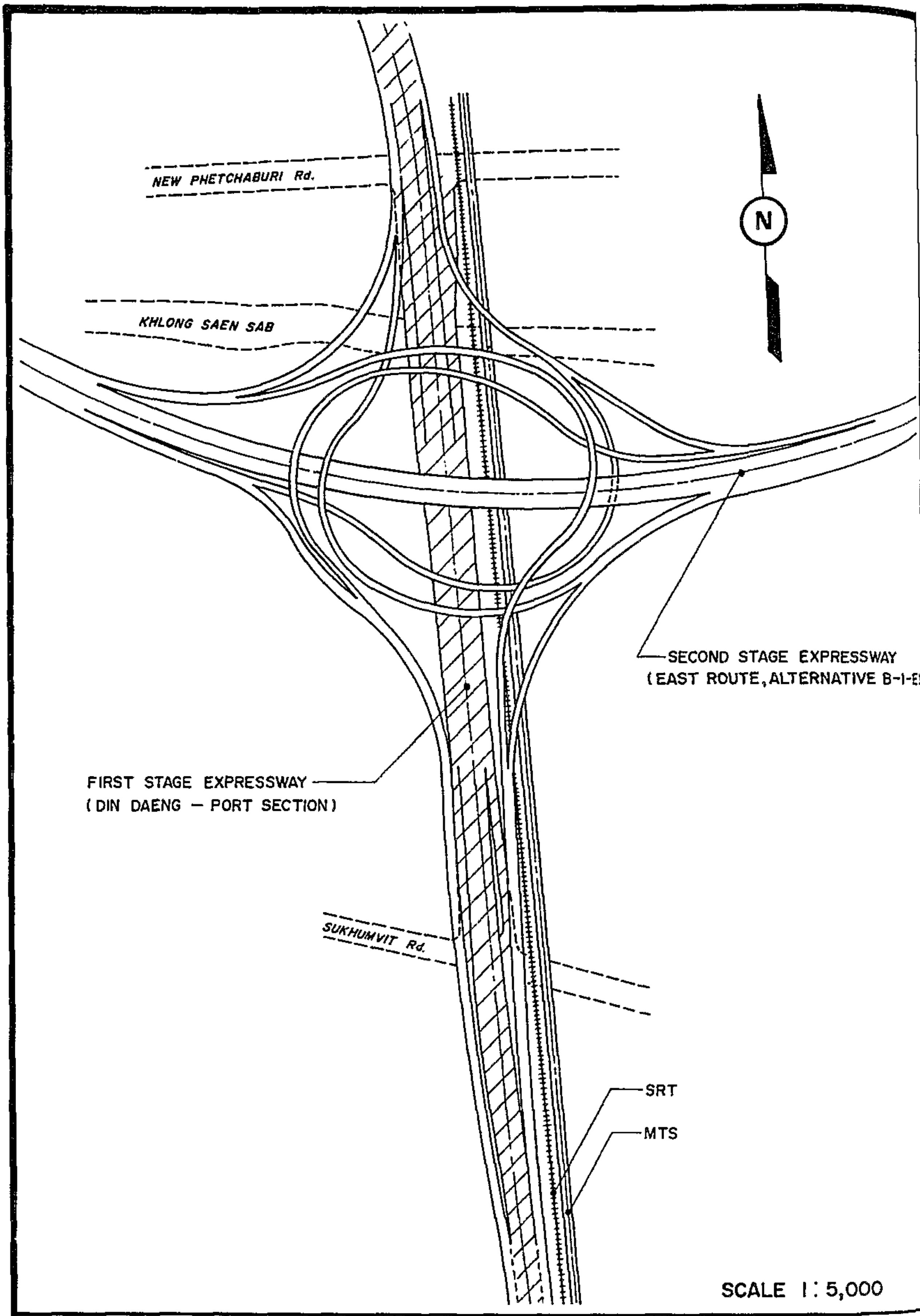


FIG. 8-3	TURBINE TYPE INTERCHANGE BETWEEN ALTERNATIVE B-1-E AND FES

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

(3) Alternative A–3–E

This route runs eastwards from Rama VI Road along Sri Ayutthaya Road and joins Alternative A–1–E at the swamp area behind the Makkasan Railway Station.

The said subcorridor along Sri Ayutthaya Road has enough width to accommodate the planned elevated expressway structure except for the on/off ramp sections.

A serious disadvantage inherent to this alternative is that the full scale demolition of built-up area which includes important public facilities such as 2–ministry complex, 2–hospital compound and 1–school is anticipated in the proposed interchange area. Therefore, this alternative was rejected from the further comparative study due to the above reasons.

(4) Alternative B–1–E

This route passes above Khlong Saen Sab from the extension of Rama VI Road eastwards to Khlong Tan, then it runs toward New Phetchaburi Road, and turn its direction northwards and terminates at the planned road by DOH just beyond the National Road No. 3344.

Due to the utilization of the ROWs of Khlong Saen Sab and the New Phetchaburi Road, the cost of land acquisition and compensation was estimated to be less than the cases of the other alternatives.

However, a great difficulty is anticipated to plan the interchange between the Din Daeng-Port Section of the FES, since the planning of large scale interchange (see Fig. 8–3 for the sketch of interchange) was necessitated and this would result in a quite expensive disposition. In addition to the foreseen excessive construction cost, the study revealed the following problems :

- Construction of interchange requires the relocation of the existing railway; and
- Shift of the planned Mass Transit System Subcorridor is necessary if the provision of on or off ramps were to be realized in the vicinity of Sukhumvit or New Phetchaburi Road.

In the eastern section, a 3.6 kilometers long stretch of Phathanakarn Road in Hua Mak will cause a big traffic problem during the period of construction and the adoption of proper diversion scheme would be required.

(5) Alternative B–2–E

This route runs along Khlong Saen Sab from the start point same as Alternative B–1–E, bends northwards to pass along Rajchaprarop Road, then turns to the east at the end of Sri Ayutthaya Road, and merges Alternative A–1–E at the swamp area behind Makkasan Railway Station.

The ROW width of 28 meters of existing Rajchaprarop Road is not sufficient to accommodate the Expressway even if it was elevated. Thus, the ROW acquisition in highly built-up area including the demolition of multi-storied buildings would become difficult problems. Also the adoption of this alternative would result in closeness to the Sa Patum Palace.

Approximately 700 meters long stretch of Rajchaprarop Road would be affected during the period of construction and the traffic diversion in this period would bring out another problem.

(6) Alternative B–3–E

This route diverges from Alternative B–1–E at about Sta. 1+500, then bends northwards traversing residential and commercial areas between Phaya Thai and Rajchaprarop Roads and joins Alternative A–3–E at Sri Ayutthaya Road.

This altered alignment to the Alternative B–3–E reduces the number of multi-storied buildings to be affected, but continuous demolition in the densely built-up commercial and residential areas is necessary. The problem is still exist with the closeness to the Sa Patum Palace and Suan Pakard Palace.

During the period of the construction, this alternative would offer less influence to the traffic flows in the existing road network than the Alternatives B–2–E and B–4–E.

(7) Alternative B–4–E

This route has also the same initial stretch as Alternative B–1–E, then turns northwards to run along Phaya Thai Road and joins Alternative A–3–E on Sri Ayutthaya Road.

The existing ROW of Phaya Thai Road between Sri Ayutthaya Road and Phetchaburi Road has not enough width to build the Expressway and requires a widenning and this would entail the demolition in congested built-up area. The closeness to the Suan Pakard Palace is same as in the Alternative B–3–E.

A section of Phaya Thai Road, 800 meters long approximately, must be operated for its half width during the period of construction.

(8) Alternative C–E

This route diverges from Alternative B–1–E just after intersecting the existing expressway, then bends toward southeast, traverses highly developed residential and commercial areas between New Phetchaburi and Sukhumvit Roads, and joins Alternative B–1–E at one (1) kilometer east of the Khlong Tan intersection.

This route will have a 6.5 kilometers long section in valuable residential district and commercial area. Therefore, a large numbers of important houses and buildings will be subject for the demolition in the acquisition of the ROW.

In reality, the demolition is likely to become a social problem if it is actually executed and the cost for compensation will be extremely high. The priority is believed to be less compared with other alternative routes.

This route will not disturb seriously the existing traffic flows during the period of construction. But this alternative was rejected from the further comparative study due to the difficulty of large scale demolition.

8.6 Comparison of Alternative Routes

Advantages and disadvantages together with the construction and ROW acquisition costs on the five (5) alternative routes for N–S Route and six (6) alternative routes for East Routes are compared (refer to Tables 8–1 and 8–2 for respective summary sheet).

8.7 Findings and Conclusion

8.7.1 Findings

(1) N–S Route

a) Alternative A–1–N will encounter the narrow lateral clearances between existing buildings and the elevated structures of the Expressway and these clearances would not provide enough space for the fire fighting and rescue operation in the emergency case. The traffic diversion and management in Silom area during the period of construction is foreseen to be very difficult.

b) Alternative A–3–N is not recommended because it doesn't conform with the development plan of the railway container freight yard in Bang Sue.

c) Alternative B–1–N is also not recommended because it would entail social problems associated with the demolition of public facilities such as temple, mosque, school and market.

d) Alternative B–2–N is the only acceptable alternative route to avoid a cemetery area. However, this alternative entails high initial cost, demolition of temple and market, less contribution to the enhancement of urban development and the poor accessibility to/from Sathon Road.

(2) East Route

a) Alternative B–1–E is not recommended because of the difficulty of the construction of the interchange which connects the Route with the First Stage Expressway System. Not only this alternative requires a vast cost for the construction of the said interchange, but also the difficulty of the relocation of the existing railway and shifting of the planned MTS subcorridor is anticipated.

b) Alternatives B–2–E and B–3–E were regarded as being unsuitable, because of their closeness to the Palace(s) and their poor route alignment characteristics as well as high initial costs (i.e. total cost of the construction and land acquisition and compensation of properties).

c) Alternative B–4–E will encounter the problems of the closeness to the Palace, traffic diversion during the period of construction, high initial cost and adverse route alignment characteristics (i.e. adverse horizontal alignment and the maximum route length).

d) Alternative A–2–E has several advantages (i.e. initial cost, traffic diversion during the period of construction, total route length and horizontal alignment) compared with the other alternatives. Thus, this alternative is recommended as the second preferred route for the East Route if the land required can be made available in the Military and Police flat areas.

8.7.2 Conclusion

(1) N–S Route

As a result of the comparison of the alternatives, it is concluded that the Alternative A–2–N is superior to the other alternatives in almost every aspect as listed below except for the comparatively high initial cost :

- Effective use of acquired ROW;
- Accessibility and the contribution to the enhancement of the urban redevelopment;
- Easier traffic diversion/management during the period of construction; and
- Shorter route length and the ease of maintenance and operation of the Expressway compared with the split route scheme of Alternative A–1–N.

(2) East Route

As a result of the comparison of the alternatives, it was concluded that the Alternative A–1–E would be recommended as the optimum East Route based on the reasons listed below :

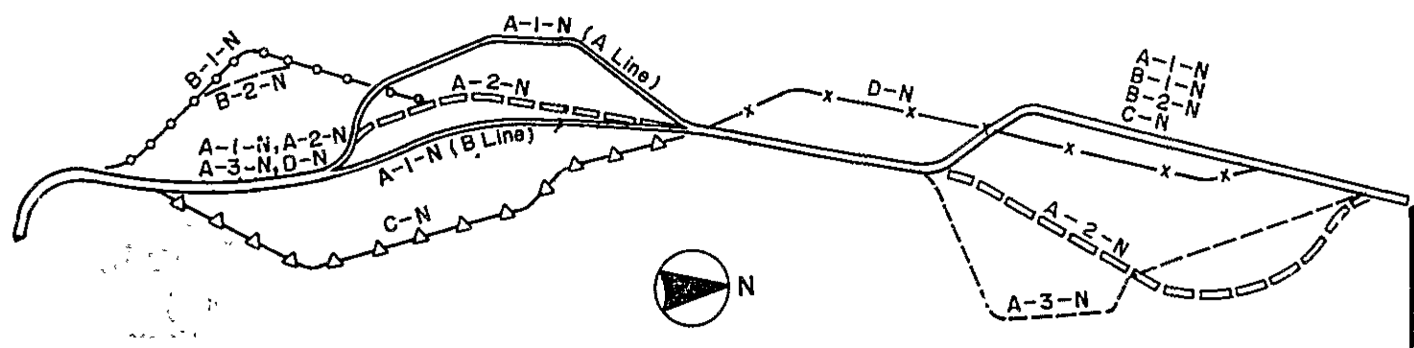
- Lower construction, land acquisition and compensation costs;
- Easier traffic diversion/management during the period of construction;
- Minimum demolition of properties;
- Shortest route length and the most true alignment to the general direction of the alignment; and
- Easier construction.

ITEM \ ALTERNATIVE LENGTH	A-1-N	▶A-2-N◀	A-3-N	B-1-N	B-2-N
	19.38 km	19.45 km	19.68 km	19.48 km	19.42 km
ALIGNMENT	Min. horizontal curve: R = 300 m (good)	Min. horizontal curve: R = 350 m (good)	Min. horizontal curve: R = 400 m (good)	Min. horizontal curve: R = 400 m (good)	Min. horizontal curve: R = 400 m (good)
CONTROL POINTS TO BE DEMOLISHED (1) PUBLIC PROPERTIES (2) BUILDINGS	- Chinese Cemetery - Peninsula Hotel (110 rooms) 1 - 3 storied 1070 units 4 storied 39 units 5 - 6 storied 7 units (normal)	- Chinese Cemetery - Victory Hotel (125 rooms) 1 - 3 storied 970 units 4 storied 38 units 5 - 6 storied 7 units 7 - 8 storied 1 unit (normal)	- Chinese Cemetery - SRT - Peninsula Hotel (110 rooms) 1 - 3 storied 890 units 4 storied 34 units 5 - 6 storied 7 units (normal)	- Sutthiwararam School - Yannawa Temple - Bang Rak Market - Mosque 1 - 3 storied 1100 units 4 storied 27 units 5 - 6 storied 2 units (difficult)	- Yannawa Temple - Bang Rak Market 1 - 3 storied 1150 units 4 storied 33 units 5 - 6 storied 2 units 7 - 8 storied 1 unit (normal)
ENVIRONMENTAL ADVERSE IMPACT	Schools 17 units Hospitals 6 units Temples etc. 6 units (medium)	Schools 15 units Hospitals 5 units Temples etc. 4 units (medium)	Schools 17 units Hospitals 6 units Temples etc. 6 units (medium)	Schools 18 units Hospitals 5 units Temples etc. 6 units (medium)	Schools 17 units Hospitals 5 units Temples etc. 6 units (medium)
INTERCHANGE	IC with FES: suitable place IC with East Route: suitable place (fair)	same as A-1-N (fair)	same as A-1-N (fair)	same as A-1-N (fair)	same as A-1-N (fair)
ACCESSIBILITY TO/FROM EXPRESSWAY, ROAD NETWORK	(good)	(good)	(good)	It is difficult to directly serve Sathon Road as Silom Road is already elevated at the crossing point with the Expressway. (fair)	(fair)
IMPACT DURING THE CONSTRUCTION (TRAFFIC DIVERSION)	Maha P. and Surasak Rd. must be closed to traffic as the ROWs are narrow (difficult)	(normal)	same as A-1-N (difficult)	(normal)	(normal)
COST (1982 PRICES) (1) CONSTRUCTION (2) RIGHT-OF-WAY (3) TOTAL (RATE)	Baht 7,060 Millions 1,540 8,600 (100%) (low)	Baht 7,054 Millions 2,035 9,089 (106%) (moderate)	Baht 7,170 Millions 1,500 8,670 (101%) (low)	Baht 7,100 Millions 2,200 9,300 (108%) (high)	Baht 7,080 Millions 2,240 9,320 (108%) (high)
RECOMMENDATION	Though initial cost is the lowest this alternative is not highly recommended due to the narrow lateral clearances to the existing buildings and difficulty of the traffic diversion around Silom area	This alternative has shorter route length and best alignment characteristic. No outstanding traffic diversion problems. Thus, the Team recommends this alternative as the preferred route if the ROW required can be made available.	This alternative does not consider the future plan of the freight yard at Bang Sue. Not straight to the general direction of the route.	This alternative follows the existing road, but so many public facilities must be demolished. This alternative is regarded as being insuitable.	If the agreement on the flyover of the cemetery is impossible, this alternative would offer the next best solution. But accessibility and contribution to the urban development is very poor.
EVALUATION (PRIORITY)	3	1	-	-	2

★

LOCATION OF ALTERNATIVES

Legend : (1) IC - Interchange
(2) FES - First Stage Expressway System
(3) SRT - State Railway of Thailand



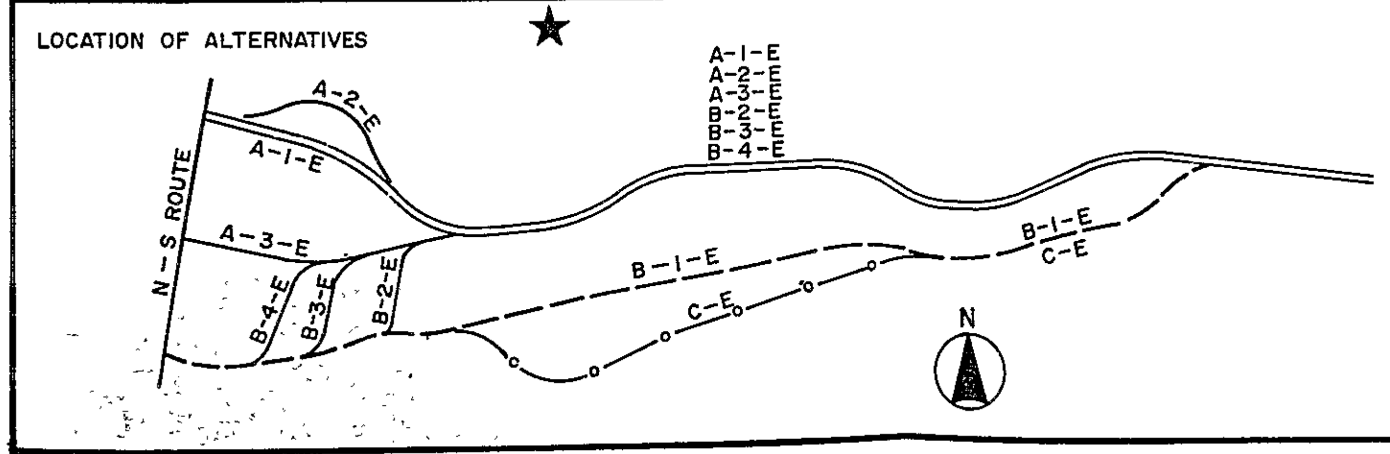
COMPARISON OF ALTERNATIVE ROUTES (NORTH - SOUTH ROUTE)

TABLE 8 - 1

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

ITEM / ALTERNATIVE / LENGTH	A-I-E	A-2-E	B-I-E	B-2-E	B-3-E	B-4-E
	14.24 km	14.44 km	14.62 km	15.15 km	15.19 km	15.22 km
ALIGNMENT	Min. horizontal curve: R = 600 m (good)	Min. horizontal curve: R = 600 m (good)	Min. horizontal curve: R = 450 m (good)	Min. horizontal curve: R = 240 m (poor)	Min. horizontal curve: R = 240 m (poor)	Min. horizontal curve: R = 240 m (poor)
CONTROL POINTS TO BE DEMOLISHED (1) PUBLIC PROPERTIES (2) BUILDINGS	1 - 3 storied 550 units 4 storied 9 units 5, 6 storied - 10 storied 1 unit (easy)	- Military Area - Police Flat 1 - 3 storied 490 units 4 storied 20 units 5, 6 storied - (difficult)	- Bangkok Mass Transit Authority 1 - 3 storied 650 units 4 storied 44 units 5, 6 storied 2 units 7, 8 storied 1 unit (average)	- Bangkok Mass Transit Authority 1 - 3 storied 630 units 4 storied 42 units 5, 6 storied 2 units (average)	- Bangkok Church 1 - 3 storied 670 units 4 storied 35 units 5, 6 storied 2 units (difficult)	- Athen Theatre 1 - 3 storied 590 units 4 storied 46 units 5, 6 storied 1 unit (average)
ENVIRONMENTAL ADVERSE IMPACT	Victory Monument (200m apart) School 1 unit Hospital 1 unit Temples, etc. 2 units (large)	School 1 unit Hospital 1 unit Temples etc. 1 unit (small)	Sa Pathum Palace (5m apart) School 6 units Hospital 2 units Temples etc. 5 units (large)	Sa Pathum Palace (5m apart) School 3 units (large)	Sa Pathum Palace (5m apart) Suan Pakkad Palace (5m apart) School 4 units Hospital 1 unit (large)	Sa Pathum Palace (5m apart) Suan Pakkad Palace (5m apart) School 4 units Hospital 2 units Temple 1 unit (large)
INTERCHANGE	IC with N-S Route: suitable place, low cost IC with FES: suitable place (good)	same as A-1-E (good)	IC with N-S Route: suitable IC with FES: high cost, complicated with railway, MTS, on-off ramps (poor)	IC with N-S Route: suitable place IC with FES: suitable place (fair)	same as B-2-E (fair)	same as B-2-E (fair)
ACCESSIBILITY TO/FROM EXPRESSWAY, ROAD NETWORK	(fair)	(fair)	Route arrives near the center of CBD and serves highly developed area. (good)	Route arrives near the center of CBD (good)	same as B-2-E (good)	same as B-2-E (good)
IMPACT DURING THE CONSTRUCTION (TRAFFIC DIVERSION)	Affects little the existing traffic flows due to new alignment. (easy)	same as A-1-E (easy)	Affects a 3.6 km long section of New Phetchaburi Road in Hua Mak. (difficult)	Affects a 600 m long section of Rajchaprarop Road (normal)	Affects a 500 m long section of Sri Ayutthaya Road. (normal)	Affects a 1.5 m long section of Sri Ayutthaya and Phaya Thai Roads. (difficult)
COST (1982 PRICES) (1) CONSTRUCTION (2) RIGHT-OF-WAY (3) TOTAL (RATE)	Baht 5,287 Millions 941 6,228 (103%) (moderate)	Baht 5,120 Millions 946 6,066 (100%) (low)	Baht 6,270 Millions 924 7,194 (119%) (high)	Baht 5,870 Millions 1,353 7,223 (119%) (high)	Baht 5,860 Millions 1,385 7,245 (119%) (high)	Baht 5,900 Millions 1,370 7,270 (120%) (high)
RECOMMENDATION	This route has many merits compared with the others. Thus, this alternative was recommended as a optimum route.	Same as Alternative A-1-E but this alternative entails the violation of military area and the demolition of Police Flats. Low initial cost.	Difficulty of relocation of the existing railway and shifting of planned MTS subcorridor. High initial cost. This alternative is regarded as being insuitable.	Closeness to the Suan Pakkad Palace. Difficultues of traffic diversion during the construction. Poor alignment. Thus, this alternative is not recommended.	Cloness to the Sa Pathum and Suan Pakkad Palaces. Poor alignment. This alternative is not recommended.	Closeness to the Suan Pakkad Palace but slightly improved. High initial cost and difficulty in the traffic diversion. No other serious control point.
EVALUATION (PRIORITY)	1	2	-	-	-	3

LOCATION OF ALTERNATIVES



Legend : (1) IC - Interchange
(2) FES - First Stage Expressway System
(3) SRT - State Railway of Thailand
(4) MTS - Mass Transit System
(5) CBD - Central Business District

COMPARISON OF ALTERNATIVE ROUTES (EAST ROUTE)

TABLE 8-2

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

Chapter 9
ENGINEERING STUDY

CHAPTER 9 ENGINEERING STUDY

9.1 General

In this Chapter, the basic concept for design standards of the Expressway together with the various outstanding engineering problems were discussed.

The engineering studies were carried out after the field investigations using topographic maps and aerial photographs.

9.2 Study Approach

Since two subcorridors for the North-South Route (N–S Route) and the East Route were sensitive to land acquisition and property compensations for the project, the right-of way (ROW) aspects were studied very carefully and were considered as an integral part of the expressway planning process.

The Phase II Study basically deal with two expressway components; the N–S Route and East Route. Both components were approached in a detailed manner consistent with a comprehensive feasibility study of the project.

The following basic approach was established to the route location considering the present situation of the subcorridors of the Expressway:

- The proposed ROW along Rama VI road must be kept unchanged as much as possible;
- The importance of the Victory Monument must be fully recognized;
- High capacity expressway and expressway interchanges should be provided at practicable locations with the minimum disturbance to the existing environment and the extraordinary expensive construction cost must be avoided; and
- Especial care must be exercised at primary control points such as palaces, ministry buildings, schools, temples, hospitals, and military facilities.

9.3 Basic Data

9.3.1 Aerial Photographs and Photo Mosaics

Aerial photographs of the project area flown in 1981 enlarged to a scale of 1:5,000 as well as the working aerial photo mosaics of the area to a scale of 1:15,000 (flown in 1979) were used in the initial stage of the route location study.

In April 1983, the provision of the uncontrolled aerial photo mosaics to a scale of 1:5,000 was carried out by a local firm, Funny Publishing Limited Partnership, to prepare the bases for the preparation of the plan.

9.3.2 Topographical Maps

Topographical maps to the scales of 1:1,000 and 1:20,000 were used for the route location study and the ground survey.

9.3.3 Ground Survey

Traverse survey along the proposed expressway centerlines in critical areas (15 km in total length) and profile leveling were conducted by a local consultant, Asian Engineering Consultants Corp., Ltd., for further preliminary engineering designs.

Traverse survey points were established at about 500-meter intervals along the proposed centerlines. Additional survey points were installed where the radii of horizontal curves were small. Spot leveling was conducted at 200-meter intervals along the centerlines. This leveling included the taking of additional elevations at abrupt changes in terrain conditions such as rivers or waterways.

9.3.4 Soils and Materials Survey

Geological study had been made to obtain general subsoil information in the study area.

The soils and materials surveys were carried out prior to the preliminary engineering design for the purpose of supplementing the available data. The field works and laboratory testing were executed by a local consultant, National Engineering Consultants, under the Supervision of the Study Team.

9.4 Design Standards

9.4.1 General

Since design standards must reflect the desired goals identified by the Government/Authority, it is preferable to apply uniform standards if these are available. However, the preparation of such design standards by the Government/Authority is still in the adjustment stage.

The road and bridge design standards described in this section were based on the Government standards already published and the usage of these standards was determined to meet the requirements for this project considering equivalent standards from countries such as U.S.A. and Japan.

The design standards are divided into the following three categories, and coverage of each subject is not intended to be a complete treatise but rather a brief exposition of the major points :

- Geometric design standard;
- Structural design standard; and
- Drainage design standard.

9.4.2 Geometric Design Standards

(1) Approaches for the Expressway Geometric Design

a) Discussions

There are two approaches to establish the geometric design standard for urban expressways in a flat terrain. One aims at high design speed (i.e. 80 km/h or more), high efficiency and greater direct benefits and the other aims at enhancement of the massive traffic volume by adopting relatively low design speed (i.e. 60 km/h or less).

The adoption of the high speed geometric design standard sometimes entails an increase of the construction, land acquisition and compensation costs. Therefore, a comprehensive comparative study was conducted in the framework of the Phase I Study.

Six alternative cases as shown in Appendix 9.1 were studied varying the following design components :

- Design speed of throughways (i.e. 80 and 60 km/h);
- Design speed of interchange ramps (i.e. 50 and 40 km/h); and
- Lane and outer shoulder widths (i.e. 3.50 m + 2.00 m and 3.25 m + 1.50 m).

b) Conclusion

The result of the above study showed that the adoption of high design standard is more beneficial since the increase of construction cost is found to be marginal. Thus, the Study Team established the basic geometric design standard to be used for the Second Stage Expressway System (SES) based on the high design standard approach.

(2) Design Speed

Design speed is the maximum safe speed that can be maintained over a specified section of the Expressway. The design speed of 80 km/h selected based on the above discussion will directly affect many geometric elements i.e. horizontal and vertical alignments, sight distance, provision of superelevation, etc. Other features such as lane width and roadside clearance are influenced by design speed but to a lesser degree.

Change of the design speed in the same design section is normally to be avoided from the safety view point. This policy was followed in this study and the same design speeds as adopted in FES were recommended by the Study Team as shown in Table 9–1.

TABLE 9–1 ADOPTED DESIGN SPEED

Category	Recommended Standard (km/h)	ETA's Standard for 1st Stage Expressway System (km/h)
Expressway, throughways	80	80
Interchange, all ramps	50	50
On/off Ramp, diagonal type	50	30 – 50
On/off Ramp, loop type	40	–

A design speed of 80 km/h is presumed to be the highest possible value for an urban expressway. A design speed of 60 km/h is presumed to be the desirable value for the rampways of the expressway interchange. However, a design speed of 50 km/h is considered to be the optimum for ramps in this case and is recommended considering the difficulty of land acquisition and the necessity for the avoidance of onerous control points.

(3) Minimum ROW Width

The right-of-way (ROW) width to be assigned to the project should anticipate all practical future functions of the Expressway. The recommended values for ROW width are the minimum functional widths for the Expressway because of expensive land acquisition and compensation cost and the anticipated difficulty due to socio-economic situations.

The minimum width proposed for each construction type of the Expressway (i.e. 6–lane or 4–lane elevated expressway and 6–lane undercrossing expressway) is shown in Table 9–2 and Figs. 9–1 and 9–2.

TABLE 9–2 MINIMUM ROW WIDTH

Construction of the Expressway	Recommended Min. ROW Width (m)
Elevated Expressway, 6–Lane	30
Elevated Expressway, 4–Lane	23
Undercrossing Expressway, 6–Lane	40

It must be noted that a desirable minimum set back distance of about 5 m from the outer faces of deck structures should be provided where the elevated expressway is planned within the existing street ROW strip to provide spaces for :

- Fire fighting and rescue operations using street network;
- Mitigation of adverse environmental impact; and
- Working space during the Expressway construction works.

Reference should be made to Subsection 9.6.3 Descriptions of Row.

(4) Lane Width

The lane width depends on the desirable lateral allowances, the size of the biggest vehicles which are forecast to run on the Expressway and the design speed, and its selection is based on operation over long periods.

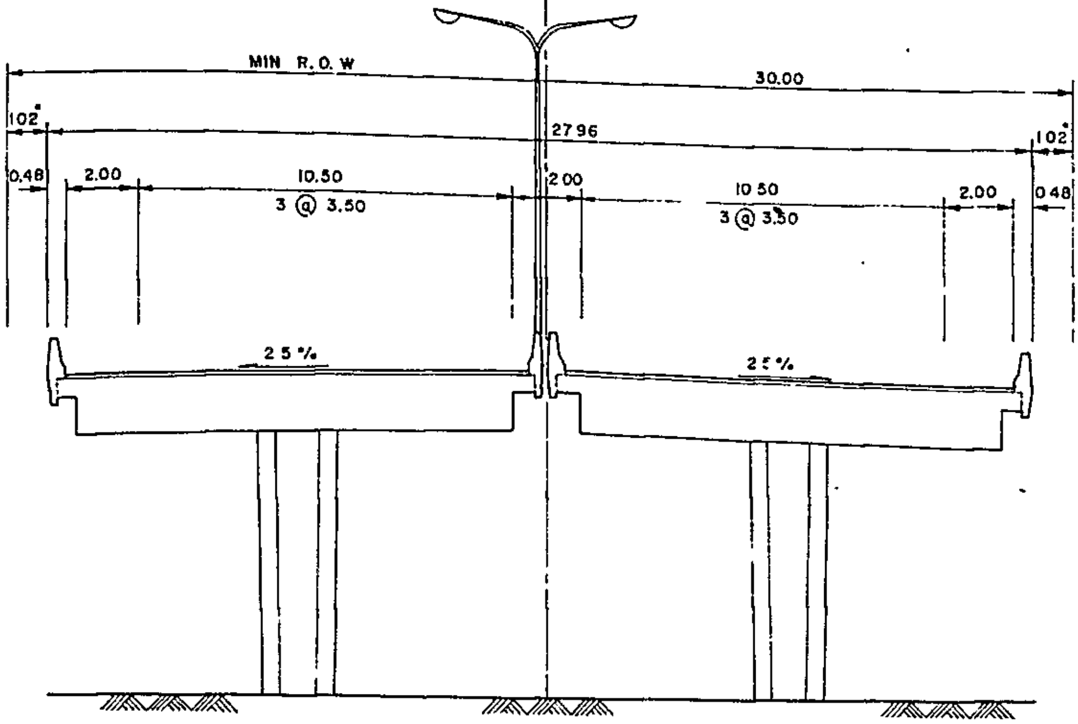
The desirable lateral allowance in case of a design speed of 80 km/h is considered to be 50 cm for each side from experience, and a maximum width of vehicles of 2.5 m applies in almost all countries. Therefore, a lane width of 3.5 m for a design speed of 80 km/h is recommended, and this meets the standard which was applied to the FES.

(5) Width of Outer Shoulder and Inner Strip

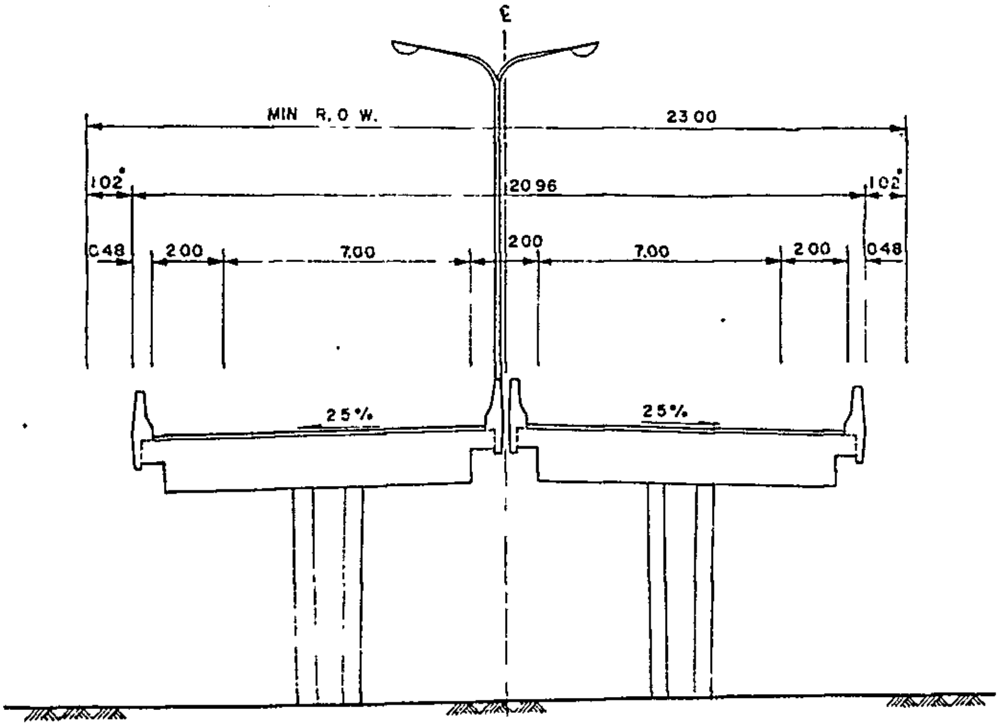
The shoulder can provide a place for vehicles to park in an emergency or when otherwise disabled, and also provides the necessary lateral clearance for the through traffic. These functions are indispensable factors contributing to safe and smooth traffic flow on roads.

If the design omits shoulders or if they are narrow, roadway capacity decreases and accident opportunity increases. During the daily peak hours all traffic lanes are in use,

6 - LANE ROAD OF ELEVATED SECTION



4 - LANE ROAD OF ELEVATED SECTION



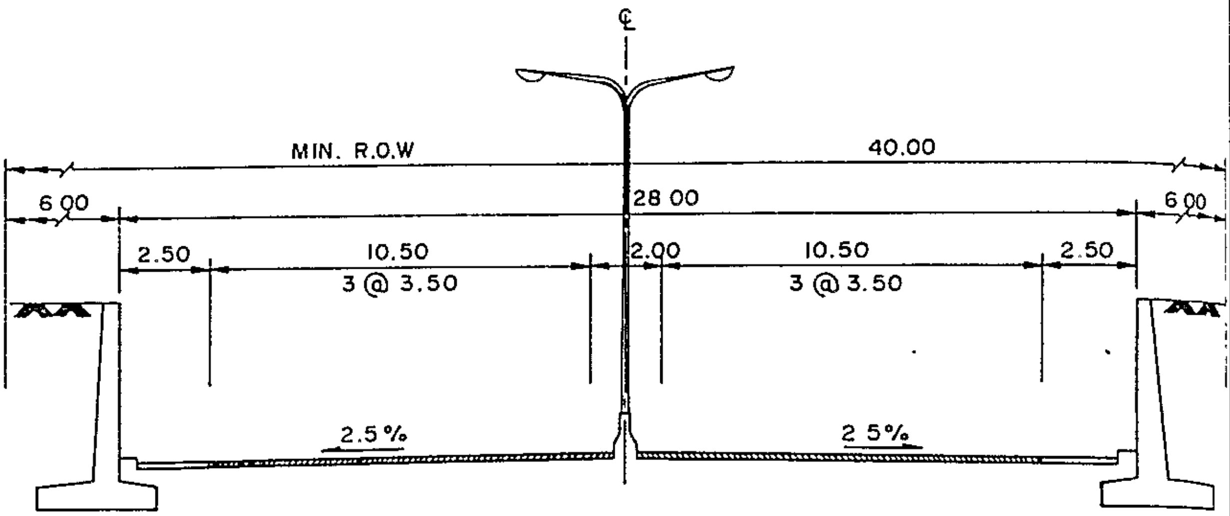
NOTE ; THE FIGURES WITH ASTERISK SHOW ABSOLUTE MINIMUM VALUES. THEY SHALL BE SUBSTITUTED BY 5 METERS OF DESIRABLE MINIMUM VALUES TO PROVIDE SET BACK DISTANCE WHERE THE VIADUCTS ARE PLANNED WITHIN THE ROW OF THE EXISTING OR PLANNED STREETS.

FIG. 9-1 SCALE 1 : 200	TYPICAL CROSS SECTIONS OF THE EXPRESSWAY(I)

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

6-LANE ROAD OF UNDERCROSSING SECTIONS

– APPROACH SECTION TO TUNNEL



– TUNNEL SECTION

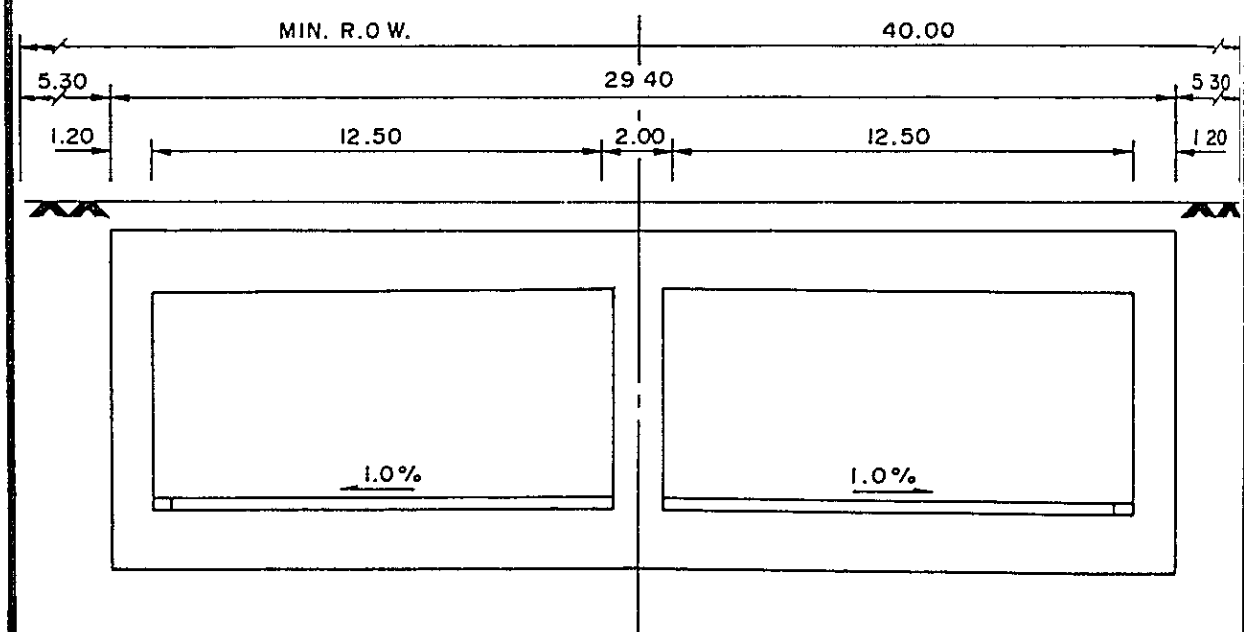


FIG. 9-2
SCALE 1:200

TYPICAL CROSS SECTIONS
OF THE EXPREESWAY (2)

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

and, where shoulders are too narrow, a stopped vehicle disrupts not only the occupied lane but all lanes in that direction.

Considering the functions of the shoulder, as well as the standard applied for the First Stage Expressway System and service level of the Expressway, 2.0 m outer shoulder and 0.33 m inner strip are recommended in this study. The outstanding conditions inherent to the project are as presented below :

- Massive traffic volume is expected on the Expressway; and
- Necessity of the adoption of a uniform design standard for the entire expressway systems.

However, after detailed study of certain locations, it was recommended that a sub-standard outer shoulder width of 1.0 m should be provided over certain lengths of the Expressway to relieve excessive ROW acquisition cost and to avoid strict primary control points in the extremely congested urban areas.

(6) Median Width

The principal functions of a median are :

- To provide an area to prevent serious accidents caused by out-of-control vehicles crossing to the opposing carriageway;
- To provide the desired freedom from interference by opposing traffic;
- To provide a barrier to prevent undesirable U-turns, which would interfere with the toll collecting system;
- To provide a space for traffic control and safety facilities such as railing, lighting columns, traffic signs and drainage system; and
- To provide a construction space in case of the elevated expressway.

The width of the median between through lane edges including the inner strip has been decided based on these functions and the condition of ROW acquisition.

A minimum median width of 2.0 m is recommended for sections of the elevated and ground level expressway.

However, a median width of 1.6 m is recommended as an absolute minimum for the elevated sections of the expressway in order to minimize ROW acquisition cost as well as to avoid serious demolition along the subcorridor (i.e. existing road) or onerous primary control points in the extremely congested urban areas.

(7) Crossfall of Carriageway

A satisfactory drainage of road surface is extremely important to safe and high speed driving during heavy rains. In general, the maximum rainfall intensity affects the value of crossfall of carriageways in tangent section.

The hourly rainfall intensity in Bangkok is observed to be higher than in cities in Japan or other countries. Therefore, a review of the standard crossfall is necessary in the study.

The relationship between maximum hourly rainfall intensity and standard crossfall is as shown in Table 9–3.

TABLE 9–3 MAXIMUM HOURLY RAINFALL INTENSITY AND CROSSFALL OF PAVED CARRIAGEWAY

City	Name of Expressway	Maximum Hourly Rainfall Intensity (mm)	Standard Crossfall %
Bangkok	First Stage Expressway System in Greater Bangkok	73.8	2.5
Jakarta	Jakarta Intra Urban Tollway	68.9	2.0
Tokyo	Tokyo Metropolitan Expressway	45.0	1.5

To ensure safe and high speed driving during heavy rains by preventing hydroplaning, a standard crossfall of 2.5 percent is recommended for the carriageways in tangent sections.

(8) Minimum Horizontal Curve Radius

A minimum radius of 240 m is recommended for the throughways which is compatible with the design speed of 80 km/h and the maximum super-elevation of 7 percent. The minimum radii of 80 m and 40 m are recommended to the design speeds of 50 km/h and 40 km/h, respectively.

(9) Maximum Gradient

Maximum gradients of 4.0 percent and 5.0 percent for the throughways and ramps, respectively, are recommended taking into account the following factors :

- Design speed;
- Maintenance of the uniform running speed in the Expressway;
- Anticipated truck ratio in the forecast traffic;
- Terrain condition; and
- Highway aesthetics and environmental aspects.

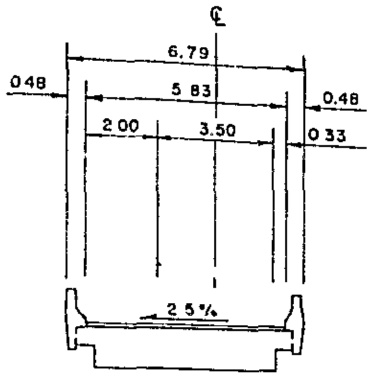
(10) Other Standard

The other main items of the recommended design standards for each design speed are presented in Tables 9–4 through 9–6.

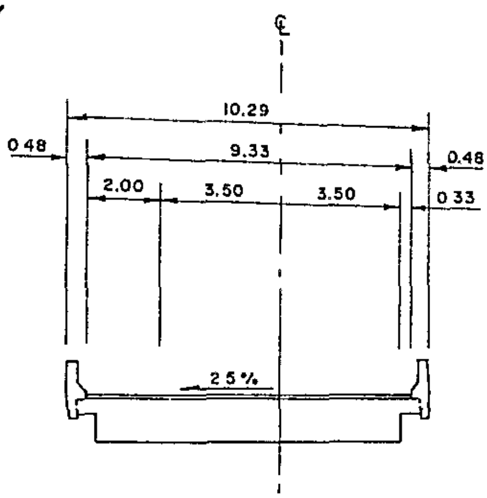
(11) Typical Cross-Section of the Expressway

Typical Cross-sectios for the Expressway based on the recommended design standards are shown in Figs. 9–1 through 9–3.

1-LANE ONE WAY



2-LANE ONE WAY



2-LANE TWO WAYS

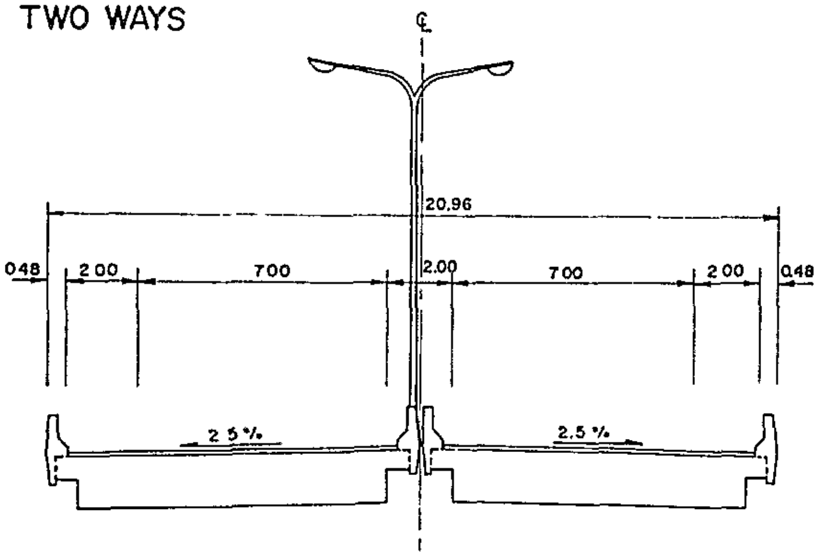


FIG. 9-3 SCALE 1:200	TYPICAL CROSS SECTIONS OF INTERCHANGE RAMPS AND ON-OFF RAMPS

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

TABLE 9–4 EXPRESSWAY GEOMETRIC DESIGN STANDARD

(Design Speed 80 km/h for Throughway)

Element	Unit	Recommended Standard	ETA's Standard for the 1st Stage Expressway System
Terrain	–	Flat	Flat
Lane Width	m	3.50	3.50
Outer Shoulder Width	m	2.00	2.00
Inner Strip Width	m	0.33	0.33
Median Width	m	2.00	2.00
Crossfall of Carriageway in Tangent Section	%	2.50	2.50
Minimum Radii (Horizontal Curve)	m	240	–
Maximum Gradient	%	4.00	4 or 5 (1)
Stopping Sight Distance	m	105 (2)	–
Minimum Vertical Clearance above Road	m	5.00	5.00

Note : (1) Gradient of 5% shows the value of absolute maximum.

(2) Stopping sight distance of 105 m shall be kept at horizontal curve by widening a cross-sectional width if necessary, as shown below :

Curve Radius (m)	Extent of Widening (m)	
	Curve Turning to Left	Curve Turning to Right
240 – 300	1.8	3.45
300 – 350	0.6	2.30
350 – 400	–	1.65
400 – 450	–	1.15
450 – 500	–	0.75
500 – 550	–	0.45
550 – 600	–	0.20

TABLE 9–5 EXPRESSWAY GEOMETRIC DESIGN STANDARD (Design Speed 50 km/h for Interchange Ramps and On/Off Ramps)

Element	Unit	Recommended Standard	ETA's Standard for the 1st Stage Expressway System
Terrain	–	Flat	Flat
Lane Width	m	3.50	3.50
Other Shoulder Width	m	2.00	2.00
Inner Strip Width	m	0.33	0.33
Median Width	m	2.00	2.00
Crossfall of Carriageway in Tangent Section	%	2.50	2.50
Minimum Radii (Horizontal Curve)	m	80	–
Maximum Gradient	%	5.00, 6.00[2]	5.00, 6.00[2]
Stopping Sight Distance	m	60[1]	–
Minimum Vertical Clearance above Road	m	5.00	5.00
Acceleration Lengths without Taper :			
Single-lane Entrance Terminal	m	160	
Two-lane Entrance Terminal	m	220	–
Deceleration Lengths without Taper :			
Single-lane Exit Terminal	m	80	–
Two-lane Exit Terminal	m	110	–

Note : (1) Stopping sight distance of 60 m shall be kept for any horizontal curve by widening the cross-sectional width, if necessary, as shown below :

Curve Radius (m)	Extent of Widening (m)	
	Curve Turning to Left	Curve Turning to Right
80 – 100	1.65	3.35
100 – 150	0.55	2.20
150 – 200	–	0.70

(2) A value of 6.00% shall be applied to the on/off ramps as an absolute maximum.

TABLE 9–6 EXPRESSWAY GEOMETRIC DESIGN STANDARD (Design Speed 40 km/h for Loop Type On/Off Ramps)

Element	Unit	Recommended Standard	ETA's Standard for the 1st Stage Expressway System
Terrain	–	Flat	Flat
Lane Width	m	3.50	3.50
Outer Shoulder Width	m	2.00	2.00
Inner Strip Width	m	0.33	0.33
Crossfall of Carriageway in Tangent Section	%	2.50	2.50
Minimum Radii (Horizontal Curve)	m	40	–
Maximum Gradient	%	6.00	–
Stopping Sight Distance	m	40(1)	–
Minimum Vertical Clearance above Road	m	5.00	5.00
Acceleration Lengths without Taper :			
Single-lane Entrance Terminal	m	160	–
Two-lane Entrance Terminal	m	220	–
Deceleration Lengths without Taper :			
Single-lane Exit Terminal	m	80	–
Two-lane Exit Terminal	m	110	–

Note (1) Stopping sight distance of 40 m shall be kept for any horizontal curve by widening a cross-sectional width, if necessary, as shown below

Curve Radius (m)	Extent of Widening (m)	
	Curve Turning to Left	Curve Turning to Right
40 – 60	1.05	2.70
60 – 80	–	1.05
80 – 100	–	0.20

9.4.3 Structural Design Standard

In the Phase I Study, the design standard of FES has been carefully reviewed.

The structural types of SES were chosen to follow similar types of FES in order to maintain the uniformity of the whole expressway structure and to obtain reasonable construction costs.

In structural design standard for SES, therefore, it was decided to adopt that of FES, as follows :

(1) Loading

a) Dead Loading

Dead loading is considered as the weight of structural elements : density of concrete (plain or reinforced) - - - 2.4 T/M^3.

b) Super Loading

Super loading is considered as the weight of pavement materials which are not structural element : density of surfacing - - - 2.3 T/M^3.

c) Live Loading

Live loading shall meet the AASHTO HS 20–44 standard.

d) Earthquake Loading

Earthquake of intensity VII on Modified Mercalli Scale to be catered for by applying an equivalent horizontal force of 0.06 W, applied in accordance with AASHTO standard. W is considered as dead and super loading.

e) Wind Loading

For the design of substructures, the following pressures are to be used and applied in accordance with AASHTO standard. They are based on a wind speed of 30.5 m/s.

Descriptions	Group 2	Group 3
Wind on superstructure	114 kg/m²	244 kg/m²
Wind on columns	91 kg/m²	195 kg/m²
Wind on live load	–	149 kg/m²

For the structures higher than 10 m above ground level the design wind speed shall be increased according to the following formula :

$$V = 33.38 \sqrt{\left(\frac{H}{18.8}\right)^{2/7}} \quad (m/s)$$

f) Temperature

A range of 25° ± 15°C shall be considered. Coefficient of thermal expansion shall be 12×10^{-6} per °C.

g) Differential Shrinkage and Creep

Stresses arising from differential shrinkage and creep shall be considered based on the authorized methods.

h) Surcharge Loading

Highway surcharge ---- 1 t/m^2

Railway surcharge ----- 5 t/m^2

(2) Materials for Structures

The main superstructures were designed in pre-stressed concrete because of the availability of local materials, maintenance and ease of construction.

The characteristics of main materials for structures were decided as follows :

Concrete:

Superstructure . . . precast pretensioned beams f'_c = 350 kg/cm^2

reinforced concrete f'_c = 240 kg/cm^2

Pile .... precast pretensioned piles f'_c = 350 kg/cm²

where f'_c is 28 day strength of a cylinder

Reinforcing Steel	:	deformed and smooth round bars
Prestressing Steel	:	stress-relieved strand or high tensile steel wire
Bearing	:	rubber bearing

(3) Vertical Clearances

a) Clearance for Expressway and Arterial Street

Minimum vertical clearance at the Expressway and arterial street underpasses are shown in Tables 9–4 thru 9–6 in Subsection 9.4.2.

b) Clearance for Railway (SRT)

The adopted minimum vertical clearance at the railway for new viaduct is 5.4 m. This requirement was obtained from the State Railway of Thailand.

c) Clearance for Mass Transit System

Minimum vertical clearance is 4.37 m from the top of rail.

d) Clearance for Navigation Water Way

Minimum vertical clearance for navigable Khlong shall be 3.5 m or at the same clearance as present.

9.4.4 Drainage Design Standard

The frequencies of rainfall which exceeds the design of the drainage systems have been determined as shown below :

Drainage System	Frequency of Occurrance
Surface water drainage	5 years
Culverts, Khlongs	25 years

9.5 Road Capacity and Number of Lanes

9.5.1 Assigned Traffic Volume

The traffic volumes predicted for the target year of 2000 were calculated as described in Chapter 6 and are presented in Table 9–7 together with traffic volumes of year 2010 for reference.

9.5.2 Road Capacity

(1) Methodology

The concept and methodology used for the road capacity analysis are based on the "Highway Capacity Manual of Highway Research Board, U.S.A.". However, some adjustment was made to reflect local conditions based on the results of studies undertaken by the "Highway Research Board, Japan", since much resemblance is found in the types and sizes of vehicles and in operating conditions in Thailand and Japan.

The flow diagram in Fig. 9–4 shows the procedure and the factors to be considered depending on the conditions of the area, type of vehicle, quality of the traffic flow and the cross section of the expressway.

The standard cross sections which influence capacity are shown in Figs. 9–1 and 9–2 and this was approved by ETA in the inception study stage of Phase II.

To get hourly design capacity of the Expressway, basic capacity, possible capacity and service level were discussed and shown in Appendix 9.2. The result of traffic capacity analysis is as shown in Table 9–8.

TABLE 9–7 TRAFFIC VOLUME AND NUMBER OF LANES

Road Section and Subsections	Forecasted Traffic Volume (veh/day) Year 2000	Year 2010	Number of Lanes
N–S ROUTE			
Bang Khlo ∿ Sathon Road	110,000	148,000	6
Sathon Road ∿ Phaya Thai	164,000	184,000	6
Phaya Thai ∿ Yan Phahol Yothin Road	156,000	174,000	6
Yan Phahol Yothin Road ∿ Middle Ring Road	132,000	157,000	6
Middle Ring Road ∿ Lad Yao	78,000	103,000	4
EAST ROUTE			
Phaya Thai ∿ Makkasan	160,000	176,000	6
Makkasan ∿ Middle Ring Road	146,000	182,000	6
Middle Ring Road ∿ Phra Khanong - Lad Phrao Road	113,000	147,000	6
Phra Khanong - Bang Kapi Road ∿ Bang Kapi - Bang Na Trad Road	41,000	55,000	4

(2) Daily Design Capacity

a) Peak Ratio (K)

The actual traffic flow on roads is not always constant but has characteristics to change by year, season, month, day and hour depending on the nature of the road.

Normally the 30th highest annual hourly traffic volume is applied for estimation of the capacity. The conversion factor from daily to hourly "K" is defined as the ratio of the 30th highest annual hourly traffic volume against the average annual daily traffic volume (AADT). In accordance with the results of the survey, a "K" value of 6.5% was used for the Expressway.

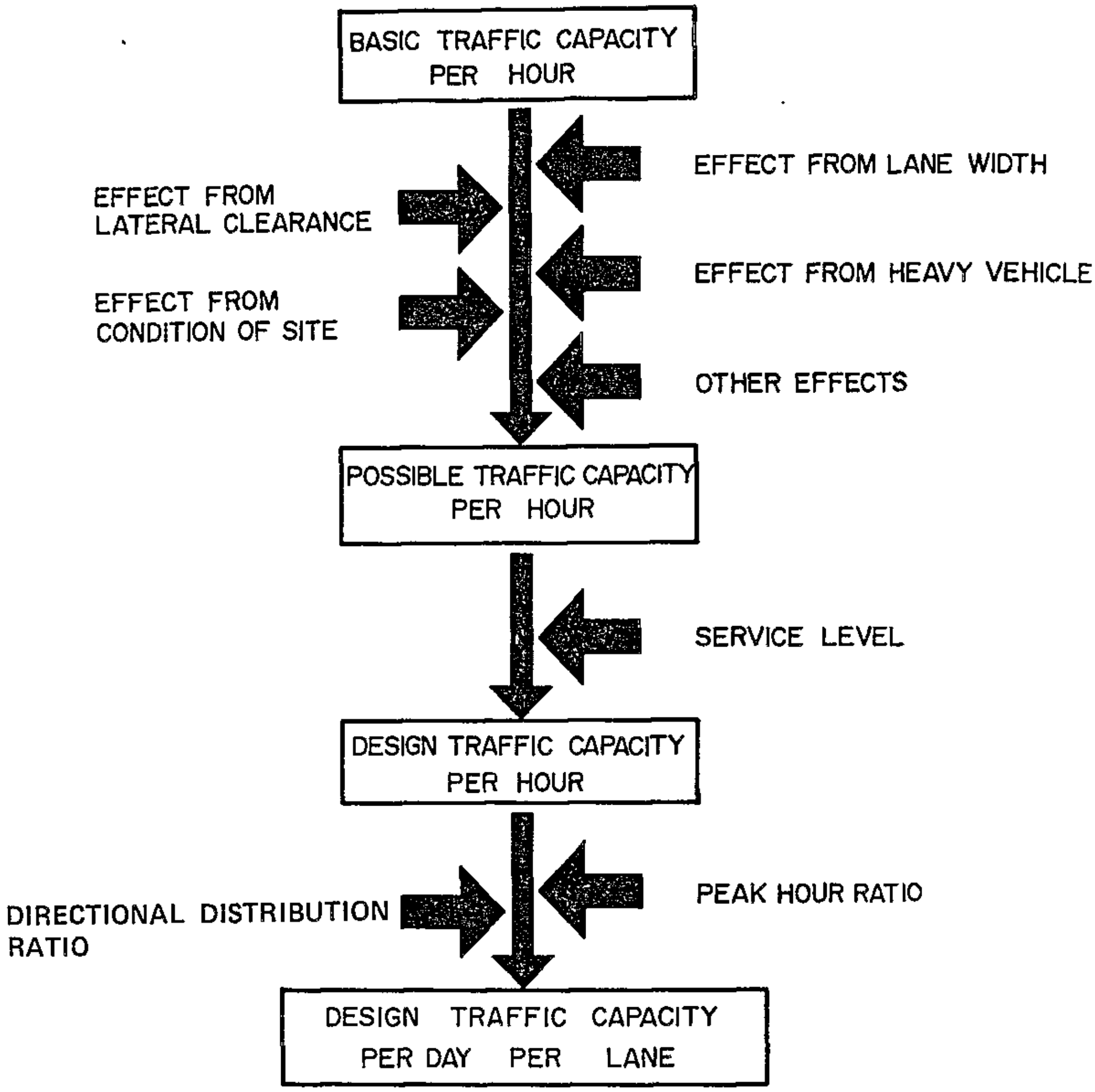


FIG. 9-4 FLOW DIAGRAM TO CALCULATE DESIGN TRAFFIC CAPACITY OF THE EXPRESSWAY

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

TABLE 9-8

TRAFFIC CAPACITY ANALYSIS FOR STUDY ROADS

ITEM	DESIGN SPEED (KM/HR)	LANE WIDTH (M)	LATERAL CLEARANCE		HEAVY VEHICLE		COEFFICIENT OF ADJUSTMENT					BASIC CAPACITY (P.C.U./HR.)	POSSIBLE CAPACITY (VEH/HR.)	SERVICE LEVEL	ADJUSTMENT OF SERVICE LEVEL	DESIGN CAPACITY (VEH/HR)	PEAK FACTOR (%)	RATE OF DIRECTION (%)	DESIGN DAILY CAPACITY (VEH/DAY) PER LANE
			Right	Left	% of H.V.	Passr Car Equiva.	Lane Width	Lateral Clear-ance	Heavy Veh.	Cond. of Sight	Total								
			(m)	(m)	Pt	Et	L	c	T	I		CB	C			CD	K	D	ADT
4 or 6 LANE 2 WAY (SERVICE LEVEL-1)	80	3.50	2.20	0.53	13	2.1	1.00	0.99	0.87	1.0	0.86	2,500	2,150	1	0.8	1,720	6.5	55	24000
4 or 6 LANE 2 WAY (SERVICE LEVEL-3)	80	3.50	2.20	0.53	13	2.1	1.00	0.99	0.87	1.0	0.86	2,500	2,150	3	1.0	2,150	6.5	55	30000
RAMP (SERVICE LEVEL-3)	50	3.50	2.20	0 53	13	2.7	1.00	0.99	0.76	1.0	0.82	2,500	2,050	3	1.0	2,050	6.5	55	28500

NOTE :

$$T = \frac{100}{100 - Pt + Et\ Pt}$$

$$C = CB . L . c . I . T$$

$$ADT\ (MULTIPLE\ LANES) = \frac{5000 \times CD}{K . D.}$$

WHERE

T: COEFFICIENT OF ADJUSTMENT FOR HEAVY VEHICLES
Pt: PERCENTAGE OF HEAVY VEHICLES
Et: PASSENGER CAR EQUIVALENT OF HEAVY VEHICLES
L: COEFFICIENT OF ADJUSTMENT FOR LAEN WIDTH
c: COEFFICIENT OF ADJUSTMENT FOR LATERAL CLEARANCE
I: COEFFICIENT OF ADJUSTMENT FOR CONDITION OF SIGHT
K: PEAK FACTOR (%)
D: RATE OF DIRECTION (%)
CD: DESIGN CAPACITY (VEH/HOUR)
CB: BASIC CAPACITY (PCU/HOUR)

b) Directional Distribution Ratio (D)

Generally speaking traffic volume is shown by total volume in two directions. However, the traffic volume in each direction is not usually the same, especially in the morning and evening peak hours. A "D" value of 55% is adopted in accordance with the result of the survey.

c) Design Capacity

Design capacity per day, per 1-lane is therefore equal to 5,000 x Design Traffic Capacity per hour ÷ (K x D). Table 9–8 shows the result of the calculations following the design concept and procedure presented in the previous paragraphs for both cases of Service Level 1(1) and Service Level 3(2).

Even if Service Level 3 is adopted, it is theoretically possible to say that during only 30 hours in 1 year (8,760 hours) does the traffic volume exceed possible capacity.

9.5.3 Determination of Number of Traffic Lanes

Taking into account physical limitation to the Expressway, the number of traffic lanes of the Expressway was calculated based on the traffic capacity analysed above and the forecast traffic volume (target year : 2000).

The number of lanes of the respective expressways were proposed as shown in Table 9–9.

The results of traffic capacity analysis show that all sections of the Expressway could enjoy the Service Level of 1 or 2 until the design target year 2000, but several sections of the Expressway would experience the Service Level of 3 in the years around 2010.

TABLE 9–9 SUMMARY OF NUMBER OF TRAFFIC LANES

Road Section	Number of Lanes
1. North-South Route (Bang Khlo – Lad Yao)	
(1) Sta. 0 + 770 – Sta. 18 + 000	6
(2) Sta. 18 + 000 – Sta. 19 + 500	4
2. East Route (Phaya Thai – Hua Mak)	
(1) Sta. 0 + 780 – Sta. 9 + 500	6
(2) Sta. 9 + 500 – Sta. 14 + 340	4

Notes: (1) Services Level 1:

At the target year of design, the annual maximum peak hour traffic volume is less than the possible capacity per hour. Vehicles in the 30th highest annual hourly volume can keep stable flow at certain speed, but selection of speed is restricted.

Service Level 2:

At the target year of design, 10th highest annual hourly traffic volume reaches possible capacity and this sometimes causes serious traffic jams during these peak ten hours. Vehicles in the 30th highest annual hourly traffic volume are unable to keep uniform speeds and the speed changes at random.

(2) Service Level 3:

At the target year of design, the 30th highest annual hourly traffic volume exceeds possible capacity and this causes serious traffic jams during these peak 30 hours. Vehicle in the flow of the 30th highest annual hourly traffic volume is always forced to change speed and sometimes is forced to stop.

9.6 Preliminary Geometric Design of Expressway

9.6.1 General

Keeping well in mind the inherent background, careful study approaches were made for the N–S Route and the East Route.

The design policies applied to both routes (i.e. the N–S Route and the East Route) are the same and are described as follows :

- Automatic use of maximum or minimum values from the design standard is not recommended because these figures in the standard are considered as limits rather than as desirable figures. To form an Expressway section that will be truly efficient and safe in operation, the aim should be a carefully tailor-made design for each section;
- Sudden changes in geometric design standard which would result in problems for motorists on the road should be avoided; and
- Where vertical and horizontal curves occur in combination or in close proximity to each other, consideration should be given to designing a flowing alignment by providing good coordination of these curves.

9.6.2 Preliminary Geometric Design

The preliminary geometric design was carried out for the A–2–N on the N–S Route and for the A–1–E on the East Route. These were recommended as a result of the finalization of the route location.

(1) Horizontal Alignment

Preliminary geometric design was carried out using the aerial photo mosaics at a scale of 1:5,000. The design of the horizontal alignment was conducted by considering the following points :

- To avoid small horizontal radii and short curve lengths between long tangent lengths;
- To provide sufficient curve length for motorists to drive easily and not to misunderstand the alignment as it is; and
- To avoid a short tangent length between two curves which bend in the same direction.

On the Drawings, the edge lines of shoulders, boundaries of right-of-way, centerline stations at 500 meter intervals, etc. are shown.

(2) Vertical Alignment

The initial study for the vertical alignment was made simultaneously with the study for horizontal alignment, after this, deliberate vertical alignment design was carried out. Basic requirements controlling the engineering aspects of the vertical alignment design were as follows :

- In areas subject to flooding, the finished grade of the roadway is maintained more than 0.5 m above the water surface;
- Minimum longitudinal gradient of 0.2% is adopted for roadway surface drainage;
- The maximum longitudinal gradient for an at-grade intersection is 2% and
- The minimum vertical clearance for grade separation structures is 5.0 m.

The vertical alignment is shown on the profile sheets at the scales of 1:500 for vertical and 1:5,000 for horizontal and presented on the Drawings. The elements of vertical alignment, gradient line, existing ground line, stations, crossing structures and the elements of the horizontal alignment were also shown on these Drawings.

9.6.3 Descriptions of the ROW

The minimum width proposed for each structure type of the Expressway (i.e. 6-lane or 4-lane elevated expressway and 6-lane undercrossing expressway) is shown as follows :

Construction of the Expressway	Recommended Minimum ROW Width (m)
Elevated Expressway, 6-lane	30
Elevated Expressway, 4-lane	23
Undercrossing Expressway, 6-lane	40

However, greater ROW widths are required at many stretches of the Expressway to provide on and off ramps and set backs for buildings.

A desirable minimum set back distance of about 5 m from the outer faces of the deck structure should be provided where the elevated expressway is planned in highly developed commercial and residential areas to provide spaces for :

- Frontage roads;
- Fire fighting and rescue operation using street network;
- Mitigation of adverse environmental impact; and
- Working space during the Expressway construction.

Typical ROW width in each stretch is shown in Appendix Fig. 9–4.

9.6.4 Consideration of Crossing Facilities

(1) Pedestrian Crossing Bridge

Major pedestrian-vehicular conflict usually occurs at intersections. On the important arterials with heavy traffic volumes the interference between pedestrians and vehicles sometimes presents serious problems in case of at-grade intersections.

Pedestrian over-bridges were proposed based on following reasons :

- Considering traffic safety for pedestrians and vehicles; and
- To relieve the extent of congestion on at-grade intersections, since the analysis of at-grade intersections as shown in section 9.9 indicates the congestion degree at

several intersections is almost 1.0 and that these intersections require grade separated facilities.

Pedestrian over-bridges at eight locations were recommended as shown below, considering physical limitation and environmental aspects :

Location			Remarks
N–S Route	STA.	4+600	Sathon Road
	STA.	6+700	Rama IV Road
	STA.	11+840	Rama VI Road
	STA.	12+540	Rama VI Road
	STA.	19+450	Super Highway
East Route	STA.	5+400	Middle Ring Road
	STA.	10+010	Phra Khanong-Bang Kapi Road
	STA.	14+340	Bang Kapi-Bang Na Trad Road

(2) Over-Bridge

In the East Route, a transition section of the Expressway between elevated section and undercrossing section separates the community into two, therefore, an over-bridge was proposed at Sta. 1+870 to provide a connection.

9.7 Preliminary Design of Interchanges

9.7.1 General

Interchange designs are generally based on the integrated considerations of traffic requirements, safety for traffic, site conditions, design controls and the geometric design standards established for the interchange ramps, as well as land acquisition and compensation cost and construction economy. Generally the priority given to each of these factors depends on the inherent environment of each interchange. For an interchange in the congested built-up area, for instance, ROW problems will be a significant factor.

After repeatedly conducted site investigations and collection of data, the Study Team selected suitable types of interchanges considering the above mentioned functions. There are several basic types of interchange and patterns of ramps for vehicle movements at a grade separation, and each type of interchange has some advantages and disadvantages.

The factors considered in selecting the type of interchange are as follows :

- Type of connecting expressway and its design speed;
- Terrain and soil conditions;
- Existing FES structures, buildings and landuse;
- Safety and efficiency of traffic; and
- Cost.

In this preliminary engineering design, three Expressway interchanges were planned.

The locations of proposed interchanges are listed as follows (Refer to the Drawings in a separate volume) :

Interchange	Expressway Connection
– Bang Khlo Interchange	Southern end of North-South Route/1st Stage Expressway (Dao Kanong-Port section)
– Phaya Thai Interchange	Western end of East Route/North-South Route
– Makkasan Interchange	East Route/1st Stage Expressway (Din Daeng-Port section)

9.7.2 Preliminary Design of Makkasan Interchange

(1) Location and Number of Lanes of Ramps

This interchange is located behind the Makkasan Railway Station and is intended to connect the East Route of the Second Stage Expressway System with the Din Daeng-Port section of the First Stage Expressway System.

(2) Types and Varieties of Interchanges

Interchanges are classified in a general way, according to the number of intersection legs, as 3-leg and 4-leg interchanges. These are further separated into more specific types as the "T", "Y" and trumpet interchanges for the 3-leg ; diamond, cloverleaf, and directional interchanges for 4-leg ; and rotary for multileg. For convenience these are grouped into two types by "with" or "without weaving ramp" and shown in Fig. 9–5.

Interchanges which utilize direct or semi-direct connections for one or more right-turning movements are termed as "directional" interchanges. Direct or semi-direct connections, as compared with loops, have shorter travel distance, higher speeds of operation, higher capacity, and they often avoid the necessity of weaving. However, in general, the construction cost is higher since two or more level structures are required.

A loop ramp has advantage to minimize the construction cost with an earthwork structure. However, careful attention must be paid to the selection of a loop ramp since it is very difficult to construct high embankments on the soft ground such as in the Bangkok Area. In general, since a large area of land is required to provide loop ramps, land acquisition cost is relatively higher.

A weaving section is a length of one-way roadway at one end of which two one-way roadways merge and at the other they separate. The weaving section is inherent to such interchange types as cloverleaf, double Y, rotary, etc., and also found between on or off-ramps. Weaving ramps may often be substituted for grade separations for some traffic movements, in which case they simplify the layout for the interchange but result in a costly arrangement in the construction. Weaving movements can be performed satisfactorily if sufficient length and width are provided in the weaving sections. Designs to eliminate weaving movements require larger and more complex structures.

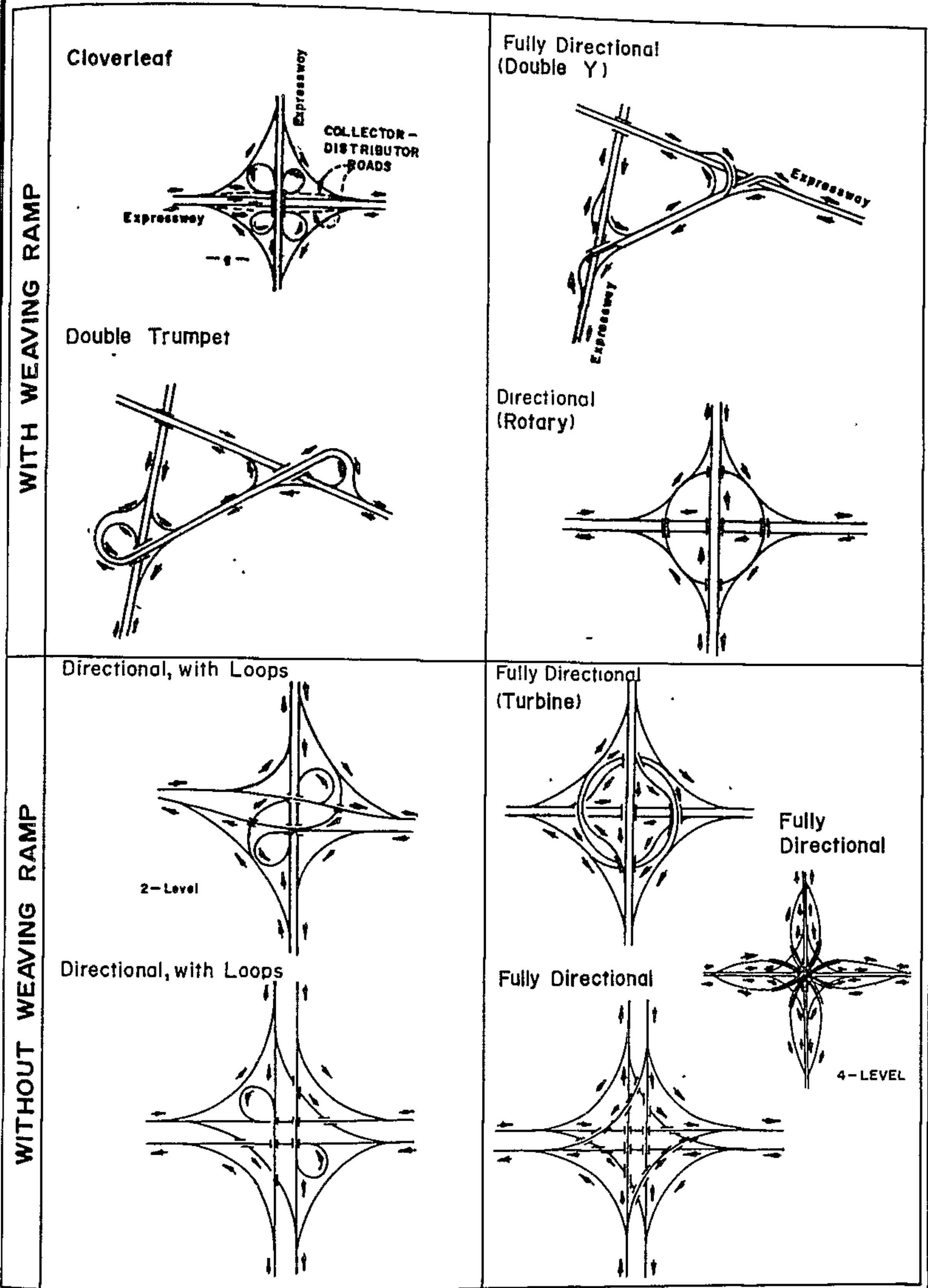


FIG. 9-5

TYPES & VARIETIES OF INTERCHANGES

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

(3) Selection of Type of Makkasan Interchange

Double Y type interchange was recommended for the following reasons :

- The swamp area behind the Makkasan Railway Station can be used to minimize the construction cost, and the land form of the available ROW does not allow the adoption of 4-leg interchange ; and
- Direct ramp is more preferable than loop ramp, considering soft ground in Bangkok since the viaduct structure was adopted in all sections of the Expressway.

(4) Number of Lanes of Ramps

The numbers of lanes of the ramps for Makkasan Interchange are recommended as shown in Fig. 9–6 based on the results of the study of estimated traffic volume.

9.7.3 Preliminary Design of Bang Khlo and Phayathai Interchanges (3-Leg Interchanges)

(1) Locations and Number of Lanes of Ramps

Bang Khlo Interchange was proposed at Bang Khlo. It has the function of connecting the North-South Route with the First Stage Expressway System (Dao Kanong-Port section).

Phaya Thai Interchange was proposed in the vicinity of the crossing point of Rama VI Road and Khlong Sam Sen, connecting the East Route with the North-South Route.

The number of lanes of a ramp for these interchanges was recommended as shown in Fig. 9–6 based on the estimated traffic volume and the consideration of the coordination of lane balance.

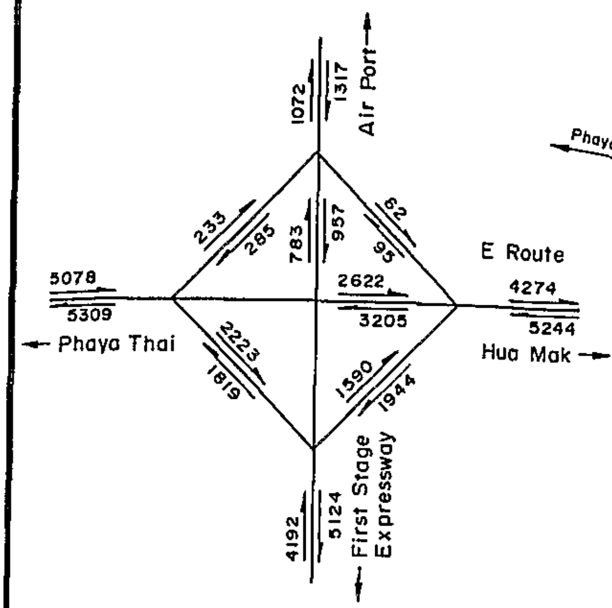
(2) Adopted 3-Leg Interchanges

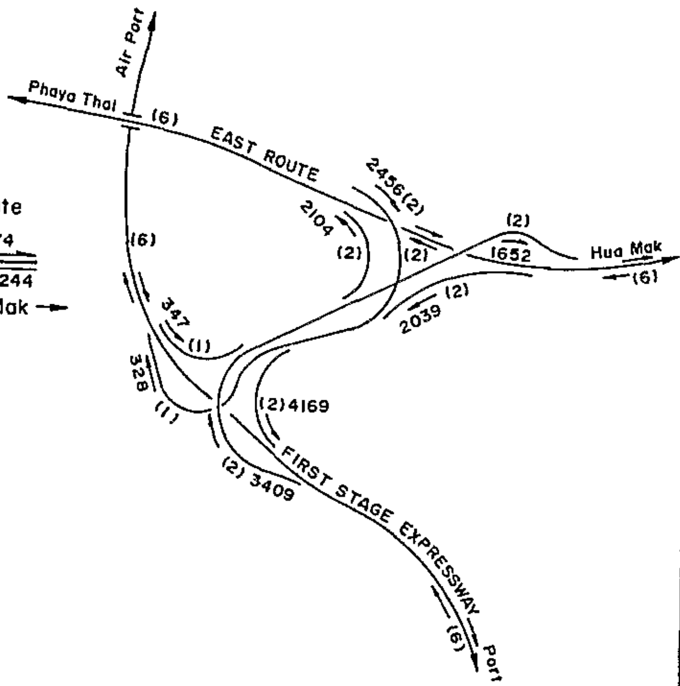
Several patterns of 3-leg interchanges may be formed by different combinations of direct, semi-directional, and loop ramps. The basic patterns presented are applicable over a wide range of intersection angles. There are two typical patterns of 3-leg interchanges : trumpet and Y-type. The trumpet pattern has loop ramp, while Y-type is composed of directional ramps. Directional ramp is preferable instead of loop ramp since the viaduct is adopted for the Expressway.

A Y-type interchange was recommended for the interchanges of Bang Khlo and Phaya Thai for the following reasons:

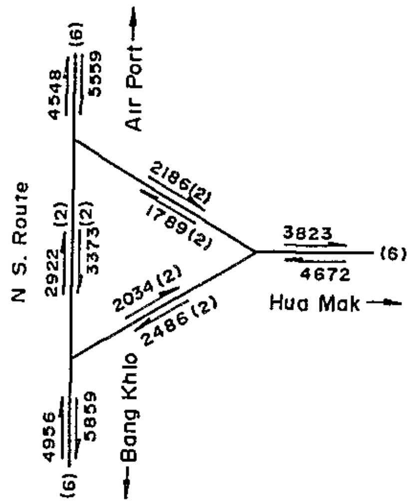
- Use of a directional ramp can reduce the construction cost, the length and the deck area of its ramp with a viaduct structure are shorter and smaller, respectively, than those of the loop ramp;
- Directional ramps can save the ROW area; and
- Higher speed of traffic can be maintained on directional ramps.

1) MAKKASAN INTERCHANGE

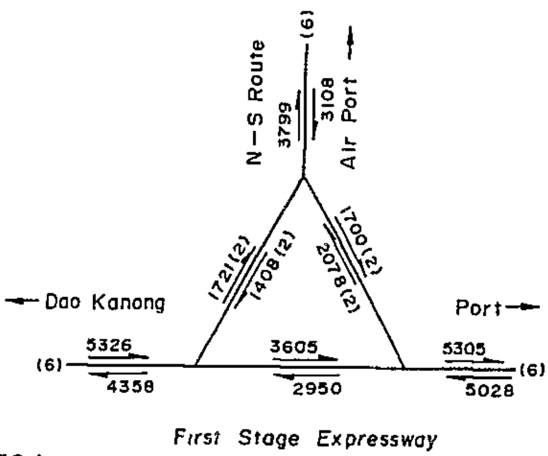




2) PHAYA THAI INTERCHANGE



3) BANG KHLO INTERCHANGE



NOTES :

1) FIGURE WITH ARROW SHOWNS VEHICLES OF HOURLY PEAK VOLUME.
2) FIGURE IN PARENTHESIS INDICATES LANE NUMBER.
3) HOURLY PEAK FACTOR; 6.5 %
4) RATE OF DIRECTIONAL TRAFFIC VOLUME; 55 %

FIG. 9-6 INTERCHANGE TRAFFIC VOLUME AND ITS NUMBER OF LANES

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

9.8 Preliminary Design of On and Off Ramps

9.8.1 General

The on and off ramps (On/Off-Ramps) which connect the Expressway with the at-grade street are planned as far as possible in the most effective locations, and should enable access and egress to be made simple and attractive to users. Fig. 9–7 shows the locations of on and off ramps.

It is confirmed that the Expressway levies on its users a flat rate tariff. This sytem is considered appropriate because the average user travels a comparatively short distance and it is a faster system at the toll collection points. With this system tollgates are needed at every On-Ramp.

Many traffic accidents on roads occur at the sections where traffic flow is disturbed or non-uniform. On/Off-Ramps is a good example, since the section involves merging, diverging and sometimes weaving manoeuvers. The provision of smooth flow of traffic at the ramp sections is therefore extremely important and this can be accomplished only by proper utilization of satisfactory design standards and choice of suitable ramp locations.

9.8.2 Traffic Volume and Number of Lanes of On/Off-Ramps

Table 9–10 shows the traffic volumes at On/Off-Ramps in the year 2000. There are three types of ramps connections and each type limits different ramp traffic capacity, they are :

- Merging type with additional lane at throughway (see Type A in Fig. 9–8);
- Connection provided with ramp terminal (see Type B in Fig. 9–8); and
- Connection with at-grade street.

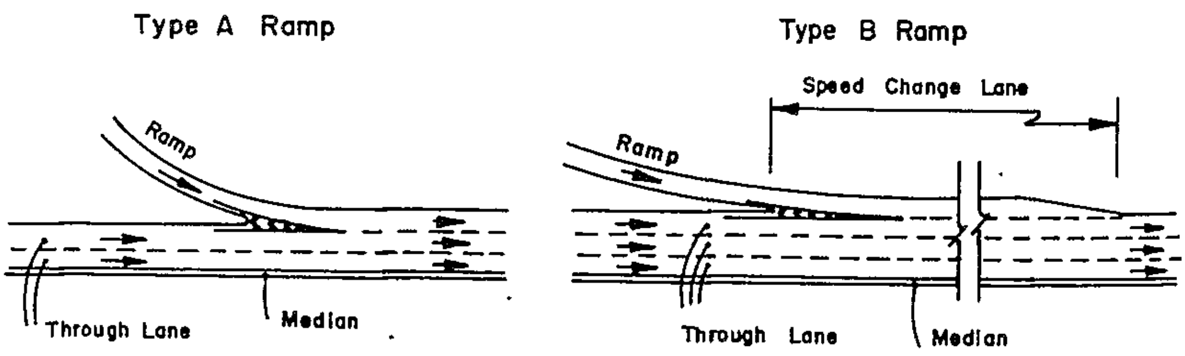


FIG. 9–8 TYPES OF RAMP TERMINAL

The traffic capacity of Type A ramp is dependent upon ramp itself. The capacities of ramps are analyzed in Table 9–8. On the other hand, the capacity of Type B ramp is limited by the terminal capacity. The capacity of 1,200 vehicles (PCU)/hour/lane was adopted for the Type B ramp based on the "Highway Capacity Manual".

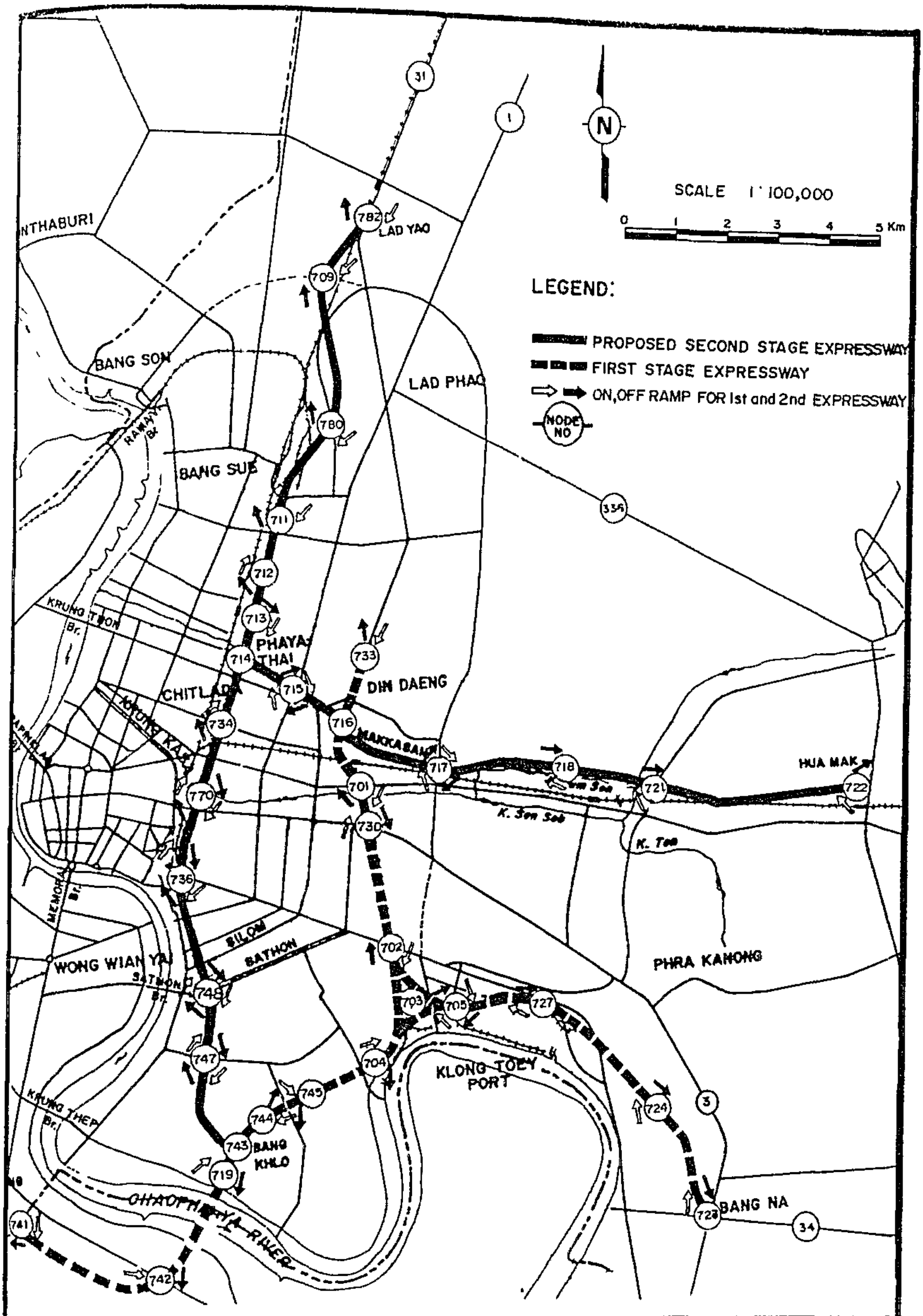


FIG. 9-7	THE LOCATIONS OF ON & OFF RAMPS

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

Based on the above discussion, the number of lanes of On/Off-Ramps was decided and tabulated in Table 9–10.

Insufficient capacity of an On-Ramp affects the traffic flow on the arterial street while the same condition for an Off-Ramp disturbs the Expressway flow. In both cases, disturbance is due to the lines of waiting vehicles reaching back to the road being left.

Waiting space will be provided in front of the toll booth and quick clearance of at-grade intersection after Off-Ramps will be planned as countermeasures to the above problem.

9.8.3 Locations and Types of On-Off Ramps

The locations of proposed On/Off-Ramps are as listed in Table 9–10.

Diagonal or loop type was recommended for the on and off ramps which connect the Expressway with arterial streets, considering the following conditions :

- Type of connecting road and its design speed;
- Existing structures, buildings and landuse; and
- Cost.

Typical types of diagonal and loop ramps are shown in Fig. 9–9.

9.8.4 Number of Toll Booths

The number of toll booths to be provided at a toll gate was computed using the service time per vehicle. The following factors were used:

- Peak hour rate : 6.5%
- Service time per vehicle (PCU) : 8.0 seconds
- Directional distribution of traffic: 55%

The result of the calculation is as shown in Table 9–11.

TABLE 9–11 NUMBER OF TOLL BOOTHS

Number of Toll Booth	Handling Capacity per Hour (vehicles)
1	450
2	900
3	1,350
4	1,800
6	2,700
8	3,600
10	4,500

Based on the above description, the number of toll booths was calculated at 73 in total for the Second Stage Expressway System. The location of the proposed toll gates are shown in the Drawings.

TABLE 9–10 TRAFFIC VOLUME AND NUMBER OF RAMP LANES AND BOOTHS

NORTH-SOUTH ROUTE

Node No. 1	Station	Provided Ramp	** Year 2000 Traffic Volume (veh/day)	Peak Traffic Volume/Ramp (veh/hour)	Number of Lanes at Each Ramp	Number of Booths at On-Ramp	Connecting Road
747	3km + 200	On and off	27,594	986	1	3	Chan Road
	3km + 600	On and Off	31,986	1,143	1	3	Chan Road
748	4km + 400	On and Off	22,757	813	1	2	Sathon Road
	4km + 900	On and Off	60,332	2,156	2	5	Sathon Road
736	6km + 500	On and Off	42,472	1,518	2	4	Rama IV Road
	7km + 500	On and Off	34,223	1,223	2	3	Extension of Rama VI Road
	8km + 300	On Ramp	14,545	945	1	3	Extension of Rama VI Road
		Off Ramp	12,181	791	1	–	
770	8km + 300	On Ramp	8,295	539	1	2	Rama VI Road
		Off Ramp	15,204	988	1	–	
734	8km + 600	On Ramp	20,002	1,300	1	3	Sri Ayutthaya Road
		Off Ramp	5,038	327	1	–	
713	11km + 900	On Ramp	8,795	572	1	2	Rama VI Road
		Off Ramp	11,864	771	1	–	
712	12km + 400	On Ramp	3,718	242	1	2	Rama VI Road
		Off Ramp	12,726	827	1	–	
711	13km + 800	On and Off	14,810	529	1	2	Yan Phahol Yothin
780	15km + 500	On and Off	30,042	1,074	1	3	BMA Road in Bang Sue Yard
	Toll Barrier on Throughway		101,677	3,634	–	9	
709	18km + 100	On and Off	23,506	840	1	–	Middle Ring Road
782	19km + 500	On and Off	78,496	2,806	2	–	Connecting with Super Highway
					TOTAL	46	

EAST ROUTE

Node No. 1	Station	Provided Ramp	** Year 2000 Traffic Volume (veh/day)	Peak Traffic Volume/Ramp (veh/hour)	Number of Lanes at Each Ramp	Number of Booths at On-Ramp	Connecting Road
715	2km + 000	On and Off	5,573	199	1	2	Phahol Yothin Road
	2km + 300	On and Off	34,676	1,239	2	3	Phahol Yothin Road
717	5km + 200	On and Off	39,979	1,429	2	4	Middle Ring Road
	5km + 600	On and Off	4,839	172	1	2	Middle Ring Road
718	7km + 000	On and Off	29,288	1,047	1	3	Road along Sam Sen Canal
721	9km + 800	On and Off	82,913	2,964	2	7	Phra Khanong –
			(43,587)*	(1,558)	(2)	(4)	Lad Phrao Road
722	14km + 000	On and Off	40,762	1,457	2	4	Bang Kapi – Bang Na Trad Road
					TOTAL	27	

Note : Peak hourly rate : 6.5%

Percentage of heavy vehicle : 13%

Directional rate of traffic : 55%

* In case of East Route to be extended to Bang Kapi-Bang Na Trad Road

** Traffic volumes in vehicle per day indicated for On and Off are total for both of on and off ramps.

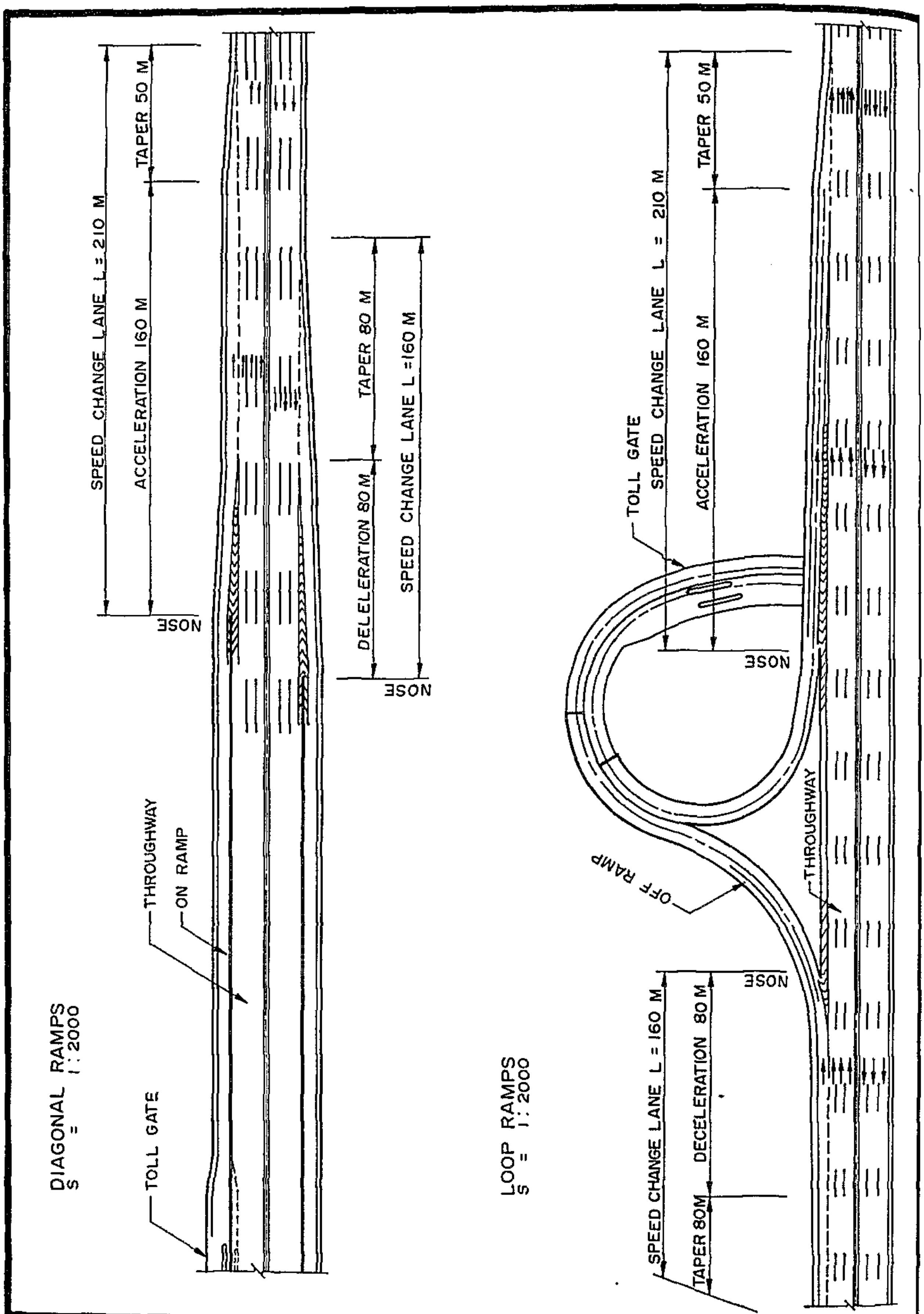


FIG. 9 – 9 TYPICAL ARRANGEMENT OF DIAGONAL AND LOOP RAMPS

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

9.9 Preliminary Design of At-grade Intersections

9.9.1 General

While the Expressway has the function of providing high-capacity, fast and free flowing routes for urban traffic movements, full benefit will not be realized unless good connections are provided between the Expressway and the arterial road system where most trips will originate and destinate. Arterial street intersections are an important part of such connections and this study considers the design of at-grade intersections directly affected by the construction of the Expressway. In view of the high traffic volumes involved and the restricted ROW, the use of free-flowing gyratory intersections is impractical and this study is restricted to the preliminary design of traffic signal intersections.

9.9.2 Estimated Traffic Volume

Traffic volume for the design year of the intersections are given in Fig. 9–10 and Appendix Fig. 9–5.

9.9.3 Capacity Analysis

The calculation of the capacity of each intersection and the procedure adopted are in accordance with the recommendations of "Highway Research Board, Plans and Designs for At-grade Intersections, Japan".

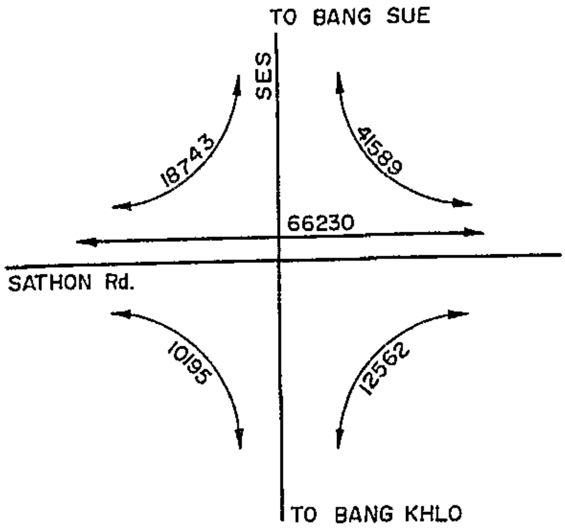
- Traffic capacity per lane :
  - Through lanes = 2,000/green hour
  - Right-turn and left-turn lanes = 1,800/green hour
- Maximum Cycle Time = 180 seconds
- Maximum integrated congestion ratio = 1.00

9.9.4 Lane Arrangement for At-grade Intersections

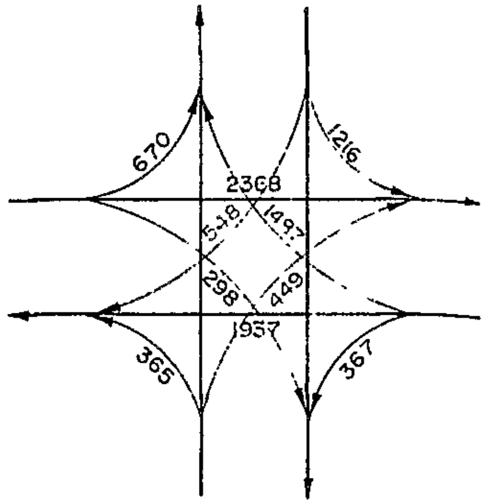
Results of the traffic signal calculation for major at-grade intersections together with lane arrangement are given as shown in Fig. 9–10. The other intersection analyses are shown in Appendix Fig. 9–5.

NODE NO. 748 YEAR : 2000

NAME OF INTERSECTION : SES (N – S) x SATHON ROAD



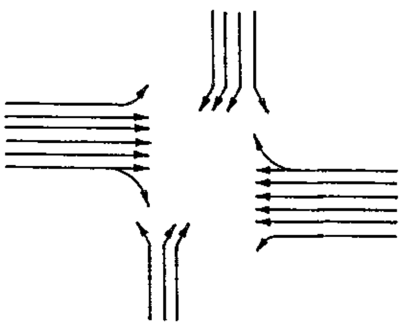
VEH/ DAY



VEH / HOUR

TRAFFIC PHASE (VEH/H)		TRAFFIC VOLUME V (PCU/H)		POSSIBLE CAPACITY Cp (PCU/H)		INTEGRATED CONGESTION RATIO Y = V/Cp	MODIFIED Y	PHASE TIME (SEC.)
1	670, 2368, 298	VL= 740 VT=2614 VR= 329	3683	1 x 1800 5 x 2000	11800	0.312*	0.39	56+2
2	1487, 1937, 367	VR= 1642 VT=2138 VL= 405	4185	1 x 1800 5 x 2000	11800	0.355*	0.44	64+2
3	548, 1216	VR= 605 (VL=1342)	605	3x1800	5400	0.112		
	365, 449	VL = 403 VR= 496	496	2x1800	3600	0.138*	0.17	24+2
				TOTAL		0.805	1.00	150

LANE ARRANGEMENT

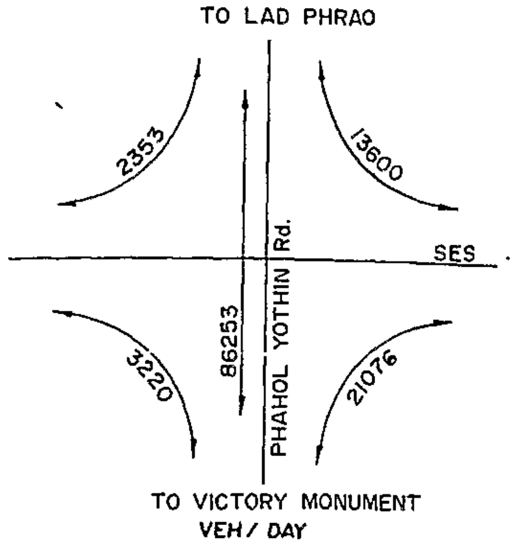


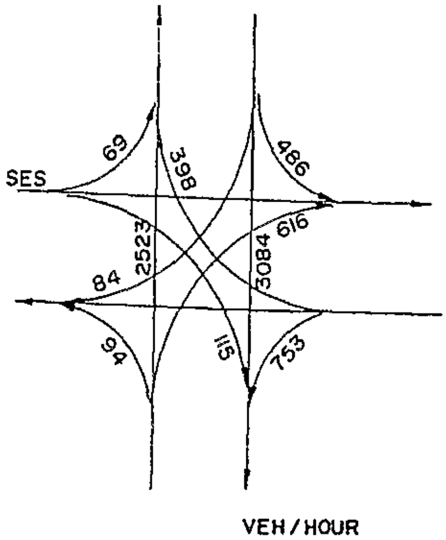
1. TRAFFIC CAPACITY PER LANE
   - THROUGH LANE = 2000 VEH (PCU)/GREEN HOUR
   - TURNING LANE = 1800 VEH (PCU)/GREEN HOUR
2. PEAK FACTOR = 6.5 %
3. PERCENTAGE OF HEAVY VEHICLES = 13.0 %
4. DIRECTIONAL DISTRIBUTION OF FUTURE DESIGN HOURLY VOLUME = 55.0 %

FIG. 9-10(1) TRAFFIC ANALYSIS OF INTERSECTION (1)

NODE NO. 715 YEAR : 2000

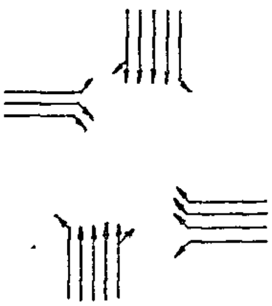
NAME OF INTERSECTION : SES (E) x PHAHOL YOTHIN ROAD





TRAFFIC PHASE (VEH/H)		TRAFFIC VOLUME V (PCU/H)		POSSIBLE CAPACITY Cp (PCU/H)		INTEGRATED CONGESTION RATIO Y = V/Cp	MODIFIED Y	PHASE TIME (SEC.)
1	84 3084 486	VR= 93 VT=3405 VL= 537	4035	1 x 1800 4 x 2000	9800	0.412 *	0.48	70+2
2	94 2523 616	VL= 104 VT=2785 VR= 680	3569	1 x 1800 4 x 2000	9800	0.364 *	0.42	61 + 2
3	69 115	(VL= 76) VR = 127	127	2 x 1800 = 3600		0.035		
	398 753	VR= 439 (VL= 831	439	3 x 1800 = 5400		0.081 *	0.10	13 + 2
			TOTAL				1.00	150

LANE ARRANGEMENT



1. TRAFFIC CAPACITY PER LANE
   THROUGH LANE = 2000 VEH (PCU)/GREEN HOUR
   TURNING LANE = 1800 VEH (PCU)/GREEN HOUR
2. PEAK FACTOR = 6.5 %
3. PERCENTAGE OF HEAVY VEHICLES = 13.0 %
4. DIRECTIONAL DISTRIBUTION OF FUTURE DESIGN HOURLY VOLUME = 55.0 %

FIG. 9-10(2) TRAFFIC ANALYSIS OF INTERSECTION (2)

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

9.10 Alternative Expressway Planning Schemes at the Victory Monument

9.10.1 General

There are two opposite concepts for the Expressway planning, namely the overcrossing scheme and undercrossing scheme. Generally, the factors which justify the final choice of these two alternatives are: effect on the community, safety of traffic, investment cost (i.e. construction and maintenance costs), utility treatment, and the management of traffic during the construction.

However, other careful considerations are also needed for such factors as the environment of the Victory Monument, Flood situation of the area and the interrelations with adjacent interchange and on and off ramps.

Fig. 9–11 shows general concepts of overcrossing and undercrossing.

9.10.2 Alternative "A" (Overcrossing Scheme)

Elevated expressway alternative which overcrosses the existing Phahol Yothin Road has been studied at the stretch between Sta. 1 + 720 and Sta. 2 + 580 of the East Route.

At present, the existing Phahol Yothin Road is a divided 6-lane street provided with sidewalk on both sides. Since two pairs of on and off ramps are to be provided to connect the Expressway and the existing Phahol Yothin Rd., a diamond type interchange arrangement is necessary at the site.

The diamond type interchange arrangement requires signal controlled at-grade intersection which connects the ramps and the Phahol Yothin Road. Therefore, the traffic movement at the intersection was taken into account in the determination of the span arrangement of the main overpassing bridge.

After the above considerations, a 3-span continuous P.C. box girder, which has a span arrangement of : 35 m + 50 m + 35 m was determined for the superstructure of the main overcrossing bridge. Side spans are composed of standard viaduct with span length of 20 m.

For determination of the type of piers, appearance from the cross street should be considered. The type of pier called "single column" is adopted for both main bridge and side spans.

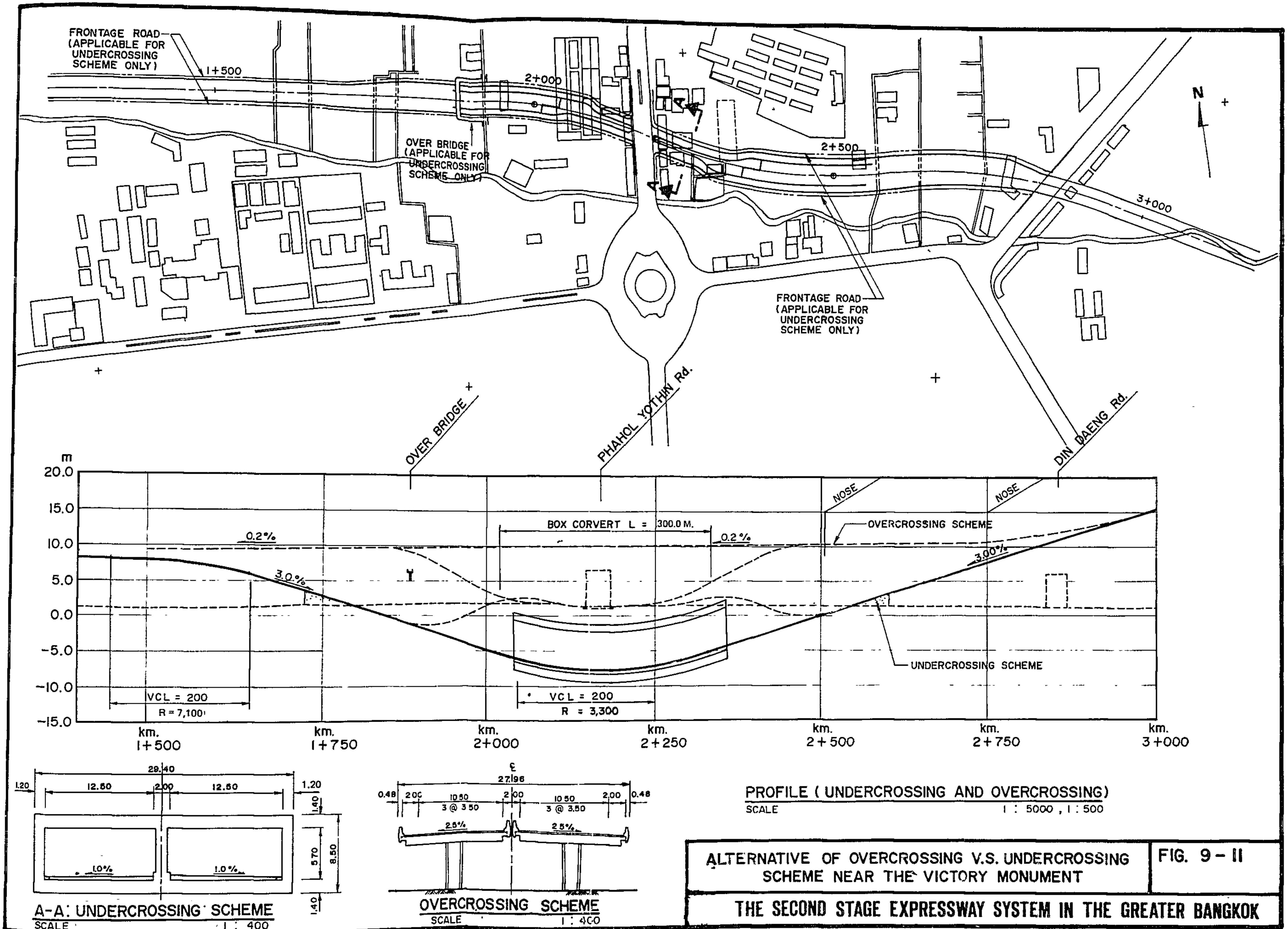
Considerations was given to the adverse soils condition in the site. Since the bearing stratum in the site is generally situated at a depth of approximately 28 m, pile foundation is used for both main bridge and side spans.

9.10.3 Alternative "B" (Undercrossing Scheme)

Undercrossing scheme has been studied at the same stretch of the East Route.

The requirement of the diamond type interchange arrangement is similar to the overcrossing scheme, the Phahol Yothin Road is situated above the Expressway in this case.

The length of undercrossing required for adequate design depends on the design speed, Expressway gradient and the amount of fall necessary to effect the grade separation. Smaller value of the Expressway gradient of 3.0% was adopted considering the traffic safety and the



ALTERNATIVE OF OVERCROSSING V.S. UNDERCROSSING SCHEME NEAR THE VICTORY MONUMENT

FIG. 9 - 11

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

adverse effect of emission gas and noise (see Fig. 9–11 for the profile).

An undercrossing structure is sometimes the cause of the separation of the community. Therefore, the frontage road is provided on each side of the Expressway together with the overbridge which connects these frontage roads to each other.

For further discussions of the undercrossing scheme, please refer to subsection 9.13.3 Study of the Undercrossing Structure and subsection 9.16.9 Drainage Study of the Victory Monument Undercrossing.

9.10.4 Appraisal of Alternatives

Appraisal of the two alternatives is shown in Table 9–12.

TABLE 9–12 APPRAISAL OF OVERCROSSING AND UNDERCROSSING SCHEMES

Item for Appraisal	Overcrossing Alternative "A" Inherent Disadvantage	Marking	Undercrossing Alternative "B" Inherent Disadvantage	Marking
Effect on Community	N/A	O	Provision of frontage road and overbridges	X
Safety of traffic	N/A	O	Poor long stretch alignment delineation	X
Construction cost	* ฿ 376 x 10^6	O	* ฿ 607 x 10^6	X
Maintenance cost	฿ 0.94 x 10^6/year	O	฿ 1.31 x 10^6/year	X
Drainage and lighting	N/A	O	Probable accident in the pump up system	X
Underground utility reconstruction	Very minor	O	Special bridges are necessary for cables, pipes and ducts	X
Trapping of traffic emissions	N/A	O	Minor	X
Traffic management during during the construction	N/A	O	Careful diversion of traffic is necessary for Phahol Yothin Road	X

Notes: 1) N/A denotes not applicable.
2) * See Appendix Table 9–2 for breakdown.
3) The mark with "O" is better than "X".

As a result of appraisal of Alternatives "A" and "B", it is found that Alternative "A" is superior to Alternative "B" in every aspect except for assthetic considerations arising from proximity to the existing Victory Monument.

As for the construction cost, the study result shows that Alternative "A" would cost only 62% of Alternative "B".

An undercrossing scheme has several disadvantages. From a community standpoint in contrast to an overcrossing scheme, many cross streets are interrupted and vehicle and pedestrian needs may make frequent overbridges necessary. Other disadvantages of Alternative "B" may include:

- Drainage and lighting problems (i.e. maintenance and probable accidents);
- Extensive and costly underground utility reconstruction;
- Trapping of undesirable traffic emissions gess; and
- Adverse effect to the traffic during the construction.
- Need for leak-proof construction.

9.10.5 Considerations for the Preservation of the Environment of the Victory Monument

Undercrossing improves the visual quality of the adjacent areas because traffic and expressway structures are removed from view, but visual quality from the users' standpoint may be reduced because aesthetic orientation advantages of a view from the Expressway are not available.

9.10.6 Conclusion

The Thai Coordination Subcommittee Members (NEB and OCMRT) requested the adoption of the undercrossing scheme. The aim was to preserve the environment of the Victory Monument which is regarded as one of the nation's most important historical features.

The undercrossing scheme would be commendable, if there were no excessive increase of cost and no problems in drainage, lighting and water exclusion but the situation is as discussed before. The adoption of this scheme could not be easily justified against the inherent disadvantages (see Table 9–12).

Therefore, it is recommended that a full scale comparative study should be done together with a complete environmental study at the time of the project execution. The studies should reflect factual environmental situations at that time. Thus the Government agencies concerned could discuss matters thoroughly and could reach the final solutions.

For the purposes of the preliminary engineering design and other studies, the Alternative "B" was adopted, since this would result in conservative, safe forecasts in the economic and financial evaluations.

9.11 Comparative Study of Viaduct and Embankment Schemes

9.11.1 General

A Comparative study has been carried out for the viaduct and embankment schemes.

In general, an embankment scheme is cheaper compared with a viaduct scheme. However, the embankment structure in a soft ground area sometimes has serious disadvantages such as embankment failure during the construction, excessive settlement after construction, and difficulty of maintenance. It also causes separation of a community.

In this subsection, the following stretches were discussed to decide the type of structure, viaduct or embankment.

N–S Route	:	Sta. 1+300 to Sta. 2+750 (L = 1.45 km)
East Route	:	Sta. 7+500 to Sta. 8+450 (L = 0.95 km) and
		Sta. 8+950 to Sta. 9+300 (L = 0.35 km)

9.11.2 Characteristics of Each Scheme

(1) Viaduct Scheme

The following design standards for the viaduct are selected for the comparative study:

- Standard superstructure of 20 m span;
- Vertical clearance of 5 m; and
- Piled foundation using precast PC piles (□50 cm) of 27.5 m average length.

(2) Embankment Scheme

The embankment scheme is based on the following conditions:

- Embankment elevation is more than 3 meters above mean sea level (MSL) considering flood level of 2 meters above MSL;
- Soil improvement method of sand drain (pact drain method) is necessary to accelelate required consolidation (i.e. within 7 months construction period);
- Surcharge of embankment 1.0 m high above finished grade is necessary; and
- Residual settlement of not more than 20 cm is permissible after the opening to traffic.

Pack drain method is adopted as shown in Fig. 9–12.

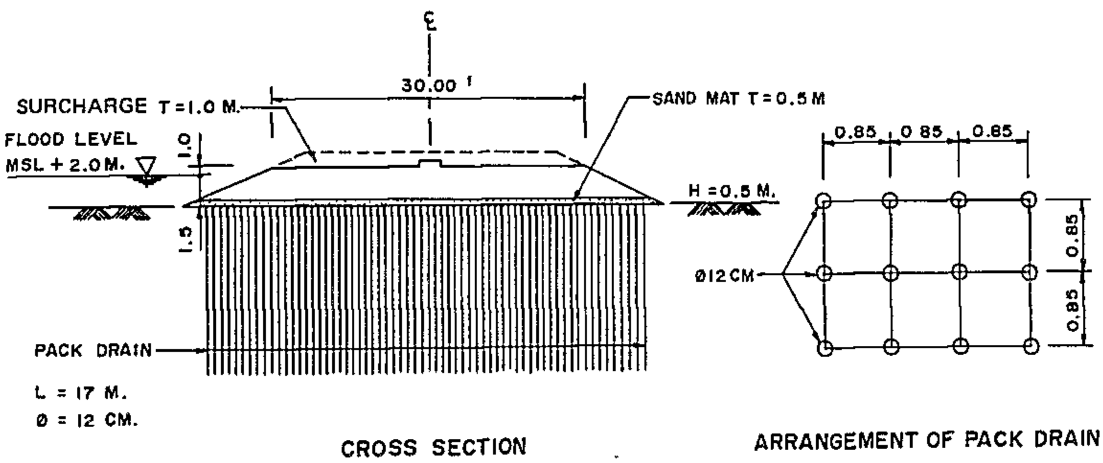


FIG. 9–12 CONCEPT OF PACK DRAIN METHOD

9.11.3 Appraisal of Alternative Schemed and Conclusion

The result of an appraisal of the two alternatives is shown in Table 9–13, considering the following points:

- Land use pattern of residential and commercial areas (i.e. community separation);
- Construction and maintenance costs; and
- Maintenanability, etc.

As a result of the comparative study it is concluded that the viaduct scheme is superior to the embankment scheme.

It must be emphasized that the free crossing of the Expressway utilizing the airspace below the viaduct is very important since these areas are close to central urbanized area and expected to become a highly developed residential and commercial areas in the new future. If the embankment scheme was chosen, the problems would arise to provide the necessary roads to connect separated communities.

TABLE 9–13 APPRAISAL OF VIADUCT AND EMBANKMENT SCHEMES

Item	Rating		Remarks
	Viaduct Scheme	Embankment Scheme	
Maintenance of Community	Good	Very poor	Embankment Scheme has demerits of separating a community and of hampering development in the vicinity.
Maintainability of Expressway	Good	Poor	Embankment alternative requires frequent maintenance due to the settlements of embankment and differential settlenents will cause problems at the approaches of the viaduct at points where embankment connects to a rigid structure.
Effect to Traffic	Good	Poor	Differential settlements make it unpleasant for motorists, and dense interval maintenance affects smooth traffic flow during repair.
Construction Cost	*238 million ฿	*134 million ฿	East Route Section between Stas. 7+500 & 8+450
Appraisal	Recommended	–	Viaduct scheme was recommended.

Note: * See Appendix Table 9–3 for breakdown.

9.12 Utilization of Spaces under the Viaduct

9.12.1 General

Availability of spaces under a viaduct is a major tool for making a new expressway fully compatible with a developed urban community. The utilization can be adapted to improve traffic situations and to serve as a stimulus to recreational space development and neighborhood redevelopment.

Several sections of the Expressway were proposed to be constructed above the existing and planned streets of BMA and DOH to save ROW cost. Therefore, the development of the Expressway sometimes requires cooperation from the agencies concerned.

The ETA may effect other utilization of the spaces under the viaduct, but cooperation with particular sectors may be considered to construct and manage non-expressway facilities such as parking lots, shopping centers, bus terminals, playgrounds, small parks, promenades, public utilities, etc. In this study, some of the non-expressway facilities have been suggested tentatively as the utilization of spaces under the Expressway.

A comprehensive study of the non-expressway facilities below the Expressway shall be conducted before the details of viaduct designs are determined since some cooperative plan may require different design criteria.

9.12.2 Joint Development Plan

Joint development plans of the Expressway and BMA (or DOH) streets were proposed in five sections as follows:

(1) Joint Development Plan of N–S Route
(Sta. 6.5 km to Sta. 7.95 km, length of 1.45 km)

As an extension of Rama VI road, BMA completed a stretch 890 m long and has a plan of construction for the remaining stretch 560 m long with a ROW width of 20 m out of the section of 1.45 km long along the N–S Route from Sta. 6.5 km to Sta. 7.95 km. For this section of 1.45 km long, a joint development plan of the Expressway and the BMA street was proposed and accepted in principle by BMA through several meetings held from March 1983 to July 1983.

The proposed joint development plan (Type I) is shown in Fig. 9–13.

(2) Other Joint Development Plans of the Expressway and Streets

Other joint development plans were proposed in four sections as indicated below:

- Type II, N–S Route from Sta. 8.95 km to Sta. 10.60 km along BMA existing street (Rama VI road);
- Type III, N-S Route from Sta.11.00 km to Sta. 13.60 km along BMA existing street (Rama VI road);
- Type IV, E-Route from Sta.7.50 km to Sta. 9.40 km along BMA planned street; and
- Type V, E-Route from Sta.10.10 km to Sta.13.70 km along DOH planned street.

Each type of joint development plans was also accepted in principle by the BMA or DOH concerned through several meetings, and shown in Fig. 9–14.

(3) Findings

There is a possibility to apply the concept of the joint development plan of the Expressway and streets to a section of N–S Route from Sta. 1.05 km to Sta. 6.5 km since the section is a newly developed corridor for the Expressway. However, the concept was not applied to the section in this study, because of the following requirements which involve much cost:

- The proposed at-grade intersections of Chan road and on/off ramps, and Sathon road and on/off ramps must be changed to grade separated interchanges, since, in addition to the traffic of Chan Road, Sathon road and on/off ramps, a huge traffic volume from a new street by the joint development plan will concentrate at the intersections; and
- Additional ROW for toll gate and operation office must be acquired.

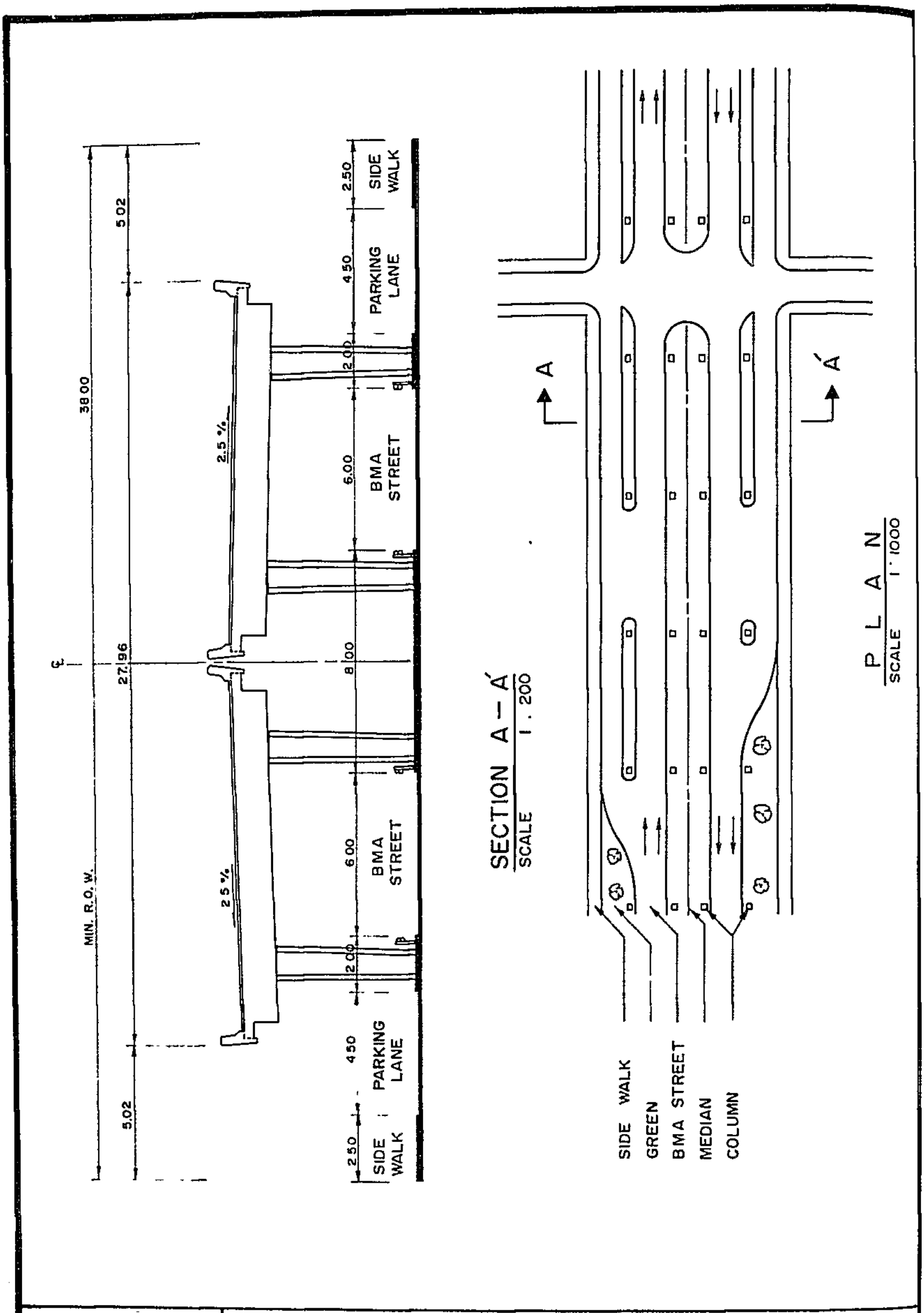
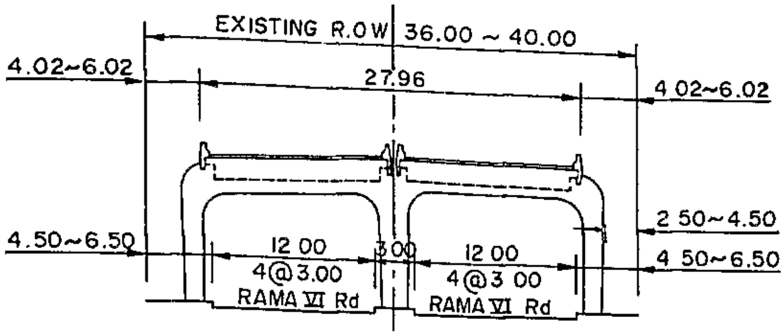
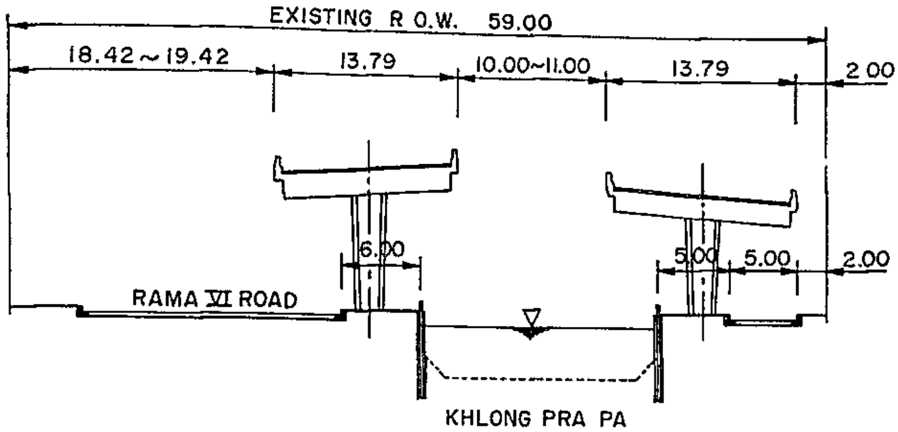


FIG. 9-13	JOINT DEVELOPMENT PLAN(TYPE I)OF THE EXPRESS -WAY AND BMA STREET WITHIN THE ROW

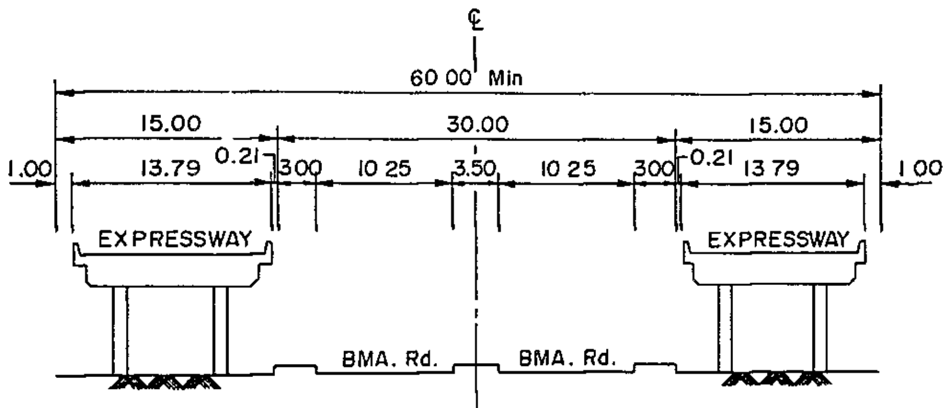
THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK



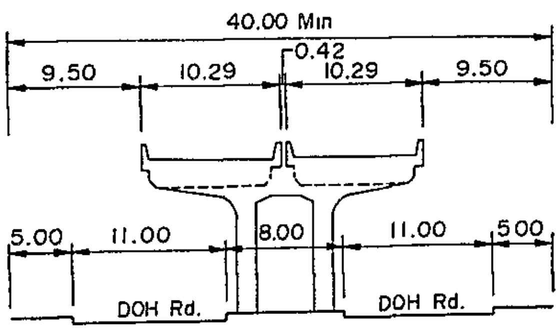
TYPE II (N-S ROUTE, STA. 8+950 TO STA. 10+600)



TYPE III (N-S ROUTE, STA 11+000 TO STA. 13+600)



TYPE IV (E ROUTE, STA. 7+500 TO STA. 9+400)



TYPE V (E ROUTE, STA. 10+100 TO STA. 13+700)

FIG. 9-14 SCALE 1 : 500	JOINT DEVELOPMENT PLANS (TYPE II, III, IV & V) OF EXPRESSWAY AND STREET WITHIN ROW

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

9.12.3 Tentative Suggestion of Non-Expressway Facilities

(1) Parking Lot and Shopping Center

Parking is an important consideration in planning an efficient urban transportation system. The private passenger car provides convenient transportation, however, this convenience depends partially on the availability of a space to park the car. Motorists searching for a parking space add considerably to the congestion of city streets.

Shopping center is also one of the useful utilizations of space under a viaduct or within an interchange in serving a community. Schematic plan of parking lot and shopping center is illustrated in Fig. 9–15.

(2) Bus Terminal

A bus terminal might be installed under the expressway viaduct making use of space available.

(3) Playground, Small Park and Promenade

Playground ranging from very small to large can be installed within the Expressway ROW where vehicles and pedestrians are physically separated for safety. A parking and promenade for walking and sitting may be developed under the viaduct and within interchange areas.

9.13 Study of Viaduct and Other Structures

9.13.1 General Concepts Adopted to Determine Viaduct Types

(1) Superstructure

a) Functional Requirements

Span Length

Minimum span length is determined by the nature of the road, railway or canal which the viaduct is required to pass over and soil conditions and surroundings. In general, the span is the most important factor affecting the choice of structure type. Once the span is fixed, then the choice is limited. In cases where the span is not fixed, then the span length which minimizes the total cost (superstructure and substructure) is selected, provided that other factors affecting the choice are equal.

Depth Ratio

A beam or girder has desirable ratio of depth to length of span which will result in minimum construction cost, and this depth ratio is generally adopted.

However, for the main span of a flyover or viaduct at which the depth is critical to determine the vertical alignment of the road, and thus affects the total cost of the structure, the minimum depth is selected.

Smooth Running Surface

To provide a smooth running surface, continuous type viaduct is desirable if there are no differential settlements. However, foundation conditions over most of the

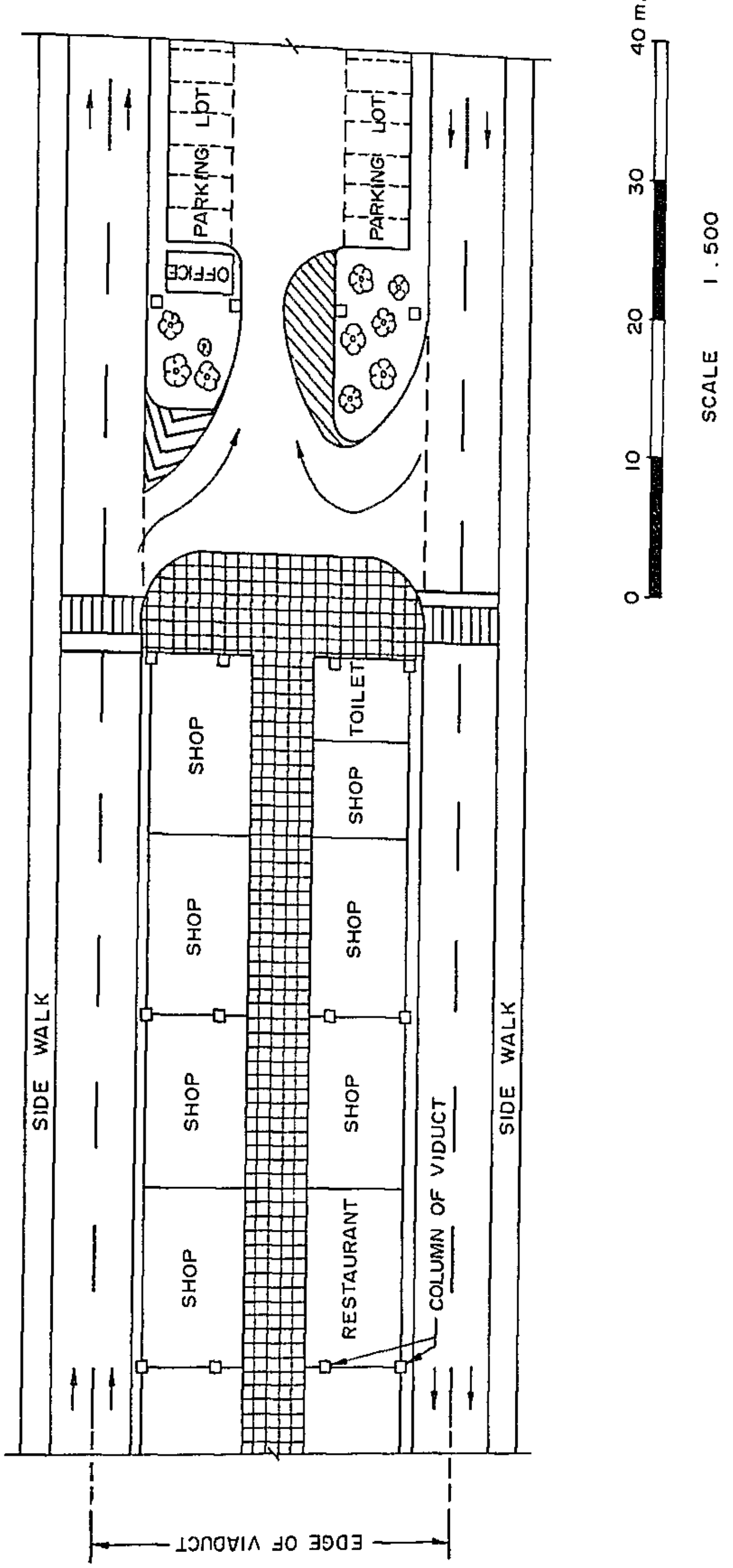


FIG. 9-15	CONCEPT PLAN OF PARKING LOT AND SHOPPING CENTER

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

routes will impose large differential settlements. To meet this difficulty various forms of construction have been considered.

b) Environmental Requirements

Construction and Maintenance

The constructional and maintenance environment is an important factor in the selection of viaduct type. Concrete bridges are generally recommended in this project because of their durability and the low level of maintenance normally experienced.

Harmony with Environment

The viaduct type which harmonizes with the surrounding environment should be adopted from the aesthetic point of view.

For flyover bridges, the structural appearance from the underside is considered. Standardization of viaduct types is also provided to create better aesthetic atmosphere.

Viaduct types in the Second Stage Expressway system should be similar to those which were constructed in the FES.

c) Construction Requirements

Availability of Material

Steel structures are not economical for short span bridges. Thus, all the alternatives considered have been of concrete construction. Both in-situ and precast designs using either reinforced or prestressed concrete are generally recommended for this project.

Construction Method

The simply supported pre-tensioned I beams with an in-situ top slab are generally recommended for construction of viaducts, because of the economy and ease of construction that local constractors are familiar with.

The full staging method should be avoided where the ground surface is soft and heavy traffic during construction is expected under the viaduct.

Construction Period

If the construction period is limited, the viaduct type should be determined by studying the measures to expedite construction.

Economic Condition

The most economical viaduct type is finally selected from the various types which satisfy the conditions mentioned above. To compare costs of various viaduct types, total construction costs of superstructure, substructure and maintenance cost are considered.

(2) Substructure

a) Pier

A reinforced concrete pier is generally used, unless special conditions must be met.

The appearance of piers is taken into account as an important factor in determining the types, especially for flyover piers.

b) Foundation

The type of foundation is determined mainly by subsoil conditions, difficulty of construction, and scale of the substructure.

Standard PC piles for viaducts are adopted based on the factors mentioned above.

9.13.2 Determination of the Design Features of Structures

(1) Superstructure

a) Viaduct of Standard Section

In the light of the points mentioned in the general concepts, the construction requirements (availability of materials, construction method, construction period, economical consideration, etc.), the standard span of viaduct in the range 20–25 m was adopted.

Subsoil conditions along most of the routes, with the large differential settlements expected, make any form of statically indeterminate structure impractical. Study Team has reviewed the structural type of the First Stage Expressway System Construction and followed its general concepts. That is, the simply supported pretensioned I beams with an in-situ top slab give the cheapest solution, and a standard span of 20 m is generally used. And it is also possible, using the standard beams, to stretch the design to 35 m without increasing the construction depth by using an in-situ portion over the columns.

b) Main Bridge of Flyover

There are several major crossings over the main arteial roads, existing railways, the planned MTS and the expressways. For these, a center span of 50 to 70 m is required, and the underside appearance is considered to be very important. So a 3-span continuous PC Box girder type was recommended as being most suitable, having regard to other factors, particularly economy of construction. The most suitable length for the side spans was investigated by means of a cost study.

The following four standard types of 3-span continuous PC Box girder were finally determined for main spans:

35–50–35 m
40–60–40 m
45–70–45 m

In general, the adoption of full staging is difficult in those areas where the superstructures ae constructed over the existing expressway or a road with heavy traffic flow, therefore, a precast method is most suitable for the construction of the superstructure.

The use of a PC T-Beam is recommended for medium span bridges (40 m), because of their ease of construction. The cantilever erection is adopted between long column piers and long center span (60–70 m) continuous bridges.

c) Pedestrian Crossing Structure

Both culvert and bridge can be considered for pedestrian crossing structures. However, culverts are generally not adopted for pedestrian crossings in this project, for the following reasons:

- Difficulty of drainage;
- Necessity of lighting;
- Attraction for criminals; and
- Difficulty to keep clean environment.

For pedestrian bridges both steel and PC structures can be considered. The steel bridge is suitable for rapid construction, however, the construction cost and maintenance cost of it are rather higher, and appearance less satisfactory than for a PC bridge. Therefore steel bridge is not recommended.

(2) Substructure

a) Pier

The concrete columns for piers are to be constructed in-situ in order to avoid traffic difficulties during construction.

Types of piers were determined in accordance with the size of superstructure, subsoil conditions and required column height. Based on the practice of the First Stage Expressway System and other data available, the piers of column type were adopted as the standard from the viewpoints of economy and ease of construction, as well as structural aesthetics.

Wall-type piers are recommended for those bridges whose width is large on skew bridges or on high bridges, because of economy and ease of construction.

b) Foundation

In general the expected load transferred to the foundation is estimated to be less than 800 ton for one substructure of 20 m span.

Such loads on the columns necessitate piled foundations. Problems of bearing capacity and settlement in the soft clay inhabit the use of shallow foundations.

Precast prestressed concrete driven piles are recommended unless the situation definitely requires the use of bored piles. Prestressed concrete piles with a cross-sectional area of less than 0.21 m^2 and a length of less than 28 m are preferable. This is to minimise problems of transportation, handling, and of soil displacement and vibration due to pile driving.

To keep settlement within the allowable limits the prestressed concrete pile tip should reach at least into the thick stiff clay layer which begins about 13 to 16 m below the gound surface. A pile with the previously mentioned cross-sectional area penetrating 10 to 12 m into the stiff clay, can have a permissible load of 100 t. The pile tip is then in either the stiff clay or the sand layer.

Based on the subsoil survey and the existing data, the following standard piles are considered for structure foundations. The allowable bearing capacities of each pile are calculated from Terzaghi's Formula.

Type			Allowable Bearing Capacity
PC pile	– 0.525 x 0.525 m	L = 26 m	100 tons
	– 0.6 m Diam.	L = 27.5 m	100 tons
	– 0.45 x 0.45 m	L = 27 m	80 tons
	– 0.35 x 0.35 m	L = 23 m	50 tons
	– 0.25 x 0.25 m	L = 20 m	25 tons

Above mentioned piles are very popular at the construction sites in Bangkok, because most of the types are prefabricated by the precast concrete fabricators. The contractors are also able to pile them easily by the normal method, that is, to use diesel hammers.

With existing construction techniques, however, the only situations where bored piles are recommended are as follows:

(i) where valuable existing facilities are located closer than 8 m from the foundation and vibration and soil diaplacement problems limit the use of driven piles.

(ii) where the transportation of long piles is extremely difficult.

(iii) where a larger capacity of pile exceeding the limit of a driven prestressed concrete pile is required.

The pile foundation should be designed on the basis of settlement control within the acceptable differential settlement. For this reason, the pile length may have to be varied according to the soils condition. In sections where large horizontal loads exist, batter piles should be used.

Negative skin friction should also be considered in the design if the side road should be liable to cause subsidence.

c) Approach Bearing Unit

Road embankments constructed on soft Bangkok clays are subject to considerable settlement. If this settlement is uniform over the length of the embankment relatively little damage is caused to the road pavement and the riding quality of the surface is maintained. However, if large differential settlenents occur between different parts of the embankment the pavement may be seriously damaged. Differential settlenents are most likely to occur at points where the ground has been previously consolidated or where the embankment connects to a rigid structure.

For differential settlement control the approaches at the at-grade/underground sections and at the at-grade/elevated sections must be provided with piled foundations.

In the interests of differential settlement casement, the pile lengths at points along the route may have to be varied. Near the adjoining structure, longer piles should be used but the lengths of the piles should be decreased to meet with the at-grade section.

The basic lengths of the approach slabs were designed in consideration of the settlements of the embankments at the slabs and the changes in the vertical profiles after settlement. The slabs are required to transmit embankment load to the piles and may be of fairly light construction, the slabs will be more effective if they are flexible and little harm will result if the slabs become cracked as settlement takes place.

9.13.3 Study of the Undercrossing Structure

(1) Cross Section and Tunnel Length

The clear height of the tunnel is 5.6 m, in accordance with the clearance for vehicles and installing space for lights.

The clear width of the undercrossing tunnel is the same for a through lane, that is escape ways are not considered necessary.

The concrete box section is generally recommended for the following reasons:

i) The box section structure of an open construction method is easy and economical to construct compared with a hored tunnel or an immersed tube tunnel.

ii) To meet the vertical alignment the depth of the tunnel is not so large and therefore an open construction method is possible.

iii) Although the construction scale is large, the same method has been applied in the past in Bangkok area and the local materials and construction techniques are available for the construction of such tunnels.

Longitudinal and cross sections are shown in Fig. 9–11.

The further alternative studies for the cross section should be conducted during the detailed engineering design.

(2) Ventilation

In general, a ventilation system should only be provided for any tunnel which is more than 500 m in length.

A ventilation system for this tunnel is therefore not necessary.

(3) Tunnel Drainage

Rain water falling on the open carriageways and ramps is collected in channels behind the tunnel entrance, from these it is taken through a pile to a pump sump at the lowest point of the bottom slab of the tunnel.

The entire undercrossing facility should be protected from storm and flood waters providing enclosure walls or special considerations to the ramp profile in such a way that no surface water would flow into the facility from the outside.

The concrete sump pit and drywell are provided with three submersible pumps and one sand pump. See subsection 9.16.9 for further details.

A transformer building with emergency generator and control rooms is provided as a supporting structure.

(4) Open Approach Drainage

Storm water in the open approaches will be collected by catch basins along the roadway and discharged into sump pits located below the roadway at tunnel portals.

In addition, intercepter cross-drains traversing throughlanes are provided to collect storm water which has bypassed the catch basin systems.

From the sump pits the water will be pumped up through a force main system to the existing khlong.

(5) Considerations for Tunnel Construction

An open construction method is recommended for the underground section as mentioned before.

The soft and very compressible Bangkok clay will cause problems in the design and construction of the underground section. For the proposed underground section, there will be two problems in the design as follows:

i) Without a proper means of stabilising the soft ground or transferring the load to the stiff clay, the underground section may be in danger of upheaval failure. The factor of safety against upheaval bearing capacity failure in the long term is lower than 2.5, as required for a permanent structure, considering the depth of stiff clay is 16 m below the ground surface.

ii) Without transferring the load to the stiff clay, large undrained deformation and subsequent time-dependent movements are expected.

The construction problem is ground settlement in a nearby area, since this would cause damage to the existing buildings.

The underground section should be constructed above either a driven pile foundation or rigid wall foundation because of the depth of the structure and the presence of nearby buildings.

The use of cast-in-situ rigid walls are recommended for the following main reasons:

i) Vibration and noise during construction are less than other methods.

ii) The rigidity of the wall is such that damage to nearby buildings or facilities is avoided.

iii) Water proofing can be so effective that the underground water talble will not be lowered.

iv) It will serve as a rigid wall foundation.

All the underground sections are situated below the underground water table and have to be waterproofed. It is proposed that waterproof concrete be used instead of any other treatment method. Water stops will be provided at all expansion and construction joints. The distance between expansion joints will be about 20 m. The alternative construction method for the tunnel section can be studied in the detailed engineering design stage.

9.13.4 Design Elements of the Planned Structures

(1) Typical Cross Sections of Bridges and Viaduct

The bridges or viaduct widths were determined based on the anticipated traffic requirement as mentioned in subsection 9–4. The typical cross section of through lane viaduct and ramp bridges are shown in Fig. 9–1 thru Fig. 9–3.

Where staged construction may be required special attention was paid to allow an appropriate spacing between earlier and later structures and to avoid possible foundation disturbance.

(2) Summary of Design Elements of Planned Bridges

The summary of design elements of planned bridges and viaduct on the N–S Route and the East Route is presented as in Tables 9–14 and 9–15.

9.14 Preliminary Design of Pavement

9.14.1 Selection of Type of Pavement

The two types of pavement, rigid and flexible, have their own advantages and disadvantages.

In general, rigid pavement has the following advantages:

- Rigid pavements do not sustain damage from water;
- Maintenance cost is low; and
- Supply of all material is available in Thailand.

On the other hand, it has disadvantages as follows:

- Each concrete slab of a rigid pavement tends to act as a unit and is subject to tilting and cracking under differential longitudinal and traverse settlenent on an embankment which is planned to provide a road above flood level; and
- Remedial work to concrete pavement is difficult and expensive.

Both rigid and flexible pavements are used in Bangkok. In general, rigid pavements appear to give better performance than flexible pavements in case of ground level roads. This may be due to possible weakness of the flexible pavement or because of the more serious effects of flooding and poor road drainage on the flexible pavement. Since it was decided that the expressway and on-off ramps are all to be elevated structures on columns, and those sections where pavements are required in this project are all located in flooding areas as indicated below, rigid pavement was adopted in two cases:

- One is a transition section of the expressway from ground level to the undercrossing structure which is always below water level; and
- The other is a ramp that connects with BMA or DOH road which is easily flooded in a rainy season.

TABLE 9–14 DESIGN FEATURES OF THE PROPOSED BRIDGES AND VIADUCT ON N-S ROUTE

1. Through Lane Viaduct

Station	Type	Span Length	Width
1+300 – 4+240	PC I-BEAM	147 @ 20	2 x 12.83
4+240 – 4+515	PC I-BEAM	11 @ 25	2 x 9.33
4+515 – 4+655	PC BOX	40+60+40	2 x 9.33
4+655 – 4+930	PC I-BEAM	11 @ 25	2 x 9.33
4+930 – 5+015	PC I-BEAM	3 @ 20	2 x 12.83
	PC I-BEAM	1 @ 25	2 x 12.83
5+015 – 5+135	PC BOX	35+50+35	2 x 12.83
5+155 – 6+600	PC I-BEAM	67 @ 20	2 x 12.83
	PC I-BEAM	5 @ 25	2 x 12.83
6+600 – 6+760	PC BOX	45+70+45	2 x 12.83
6+760 – 7+905	PC I-BEAM	51 @ 20	2 x 12.83
	PC I-BEAM	5 @ 25	2 x 12.83
7+905 – 8+000	PC I-BEAM	30+35+30	2 x 12.83
8+000 – 8+250	PC I-BEAM	10 @ 25	2 x 12.83
8+250 – 8+850	PC I-BEAM	30 @ 20	2 x 12.83
8+850 – 8+945	PC I-BEAM	30+35+30	2 x 12.83
8+945 – 9+040	PC I-BEAM	10 @ 25	2 x 12.83
9+040 – 9+290	PC I-BEAM	30+35+30	2 x 12.83
9+290 – 9+515	PC I-BEAM	9 @ 25	2 x 12.83
9+515 – 9+610	PC I-BEAM	30+35+30	2 x 12.83
9+610 – 10+385	PC I-BEAM	31 @ 25	2 x 12.83
10+385 – 10+480	PC I-BEAM	30+35+30	2 x 12.83
10+480 – 13+830	PC I-BEAM	134 @ 25	2 x 12 83
13+830 – 13+970	PC BOX	40+60+40	2 x 12.83
13+970 – 14+520	PC I-BEAM	22 @ 25	2 x 12.83
14+520 – 17+440	PC I-BEAM	146 @ 20	2 x 12.83
17+440 – 17+900	PC I-BEAM	3 @ 20	2 x 12.83
	PC I-BEAM	16 @ 25	2 x 12.83
17+900 – 18+170	PC I-BEAM	1 @ 20	2 x 9.33
	PC I-BEAM	10 @ 25	2 x 9.33
18+170 – 18+265	PC I-BEAM	30+35+30	2 x 9.33
18+265 – 19+390	PC I-BEAM	45 @ 25	2 x 9.33

2. Interchange Bridge

1+000	PC I-BEAM	@25	9.33

3. Pedestrian Bridge

STA. 4+600	Sathon Road
STA. 6+700	Rama IV Road
STA. 11+840	Rama VI Road
STA. 12+540	Rama VI Road
STA. 19+450	Super Highway

TABLE 9-15 DESIGN FEATURES OF THE PROPOSED BRIDGES AND VIADUCT ON EAST ROUTE

1. Through Lane Viaduct

Station	Type	Span Arrangement (m)	Width (m)
1+500 – 1+740	PC I-BEAM	12 @ 20	2 x 12.83
2+620 – 2+815	PC I-BEAM	6 @ 20	2 x 12.83
	PC I-BEAM	3 @ 25	2 x 12.83
2+815 – 2+910	PC I-BEAM	30+35+30	2 x 12.83
2+910 – 3+120	PC I-BEAM	8 @ 20	2 x 12.83
	PC I-BEAM	2 @ 25	2 x 12.83
3+120 – 3+215	PC I-BEAM	30+35+30	2 x 12.83
3+215 – 3+540	PC I-BEAM	15 @ 20	2 x 12.83
	PC I-BEAM	1 @ 25	2 x 12.83
3+540 – 3+940	PC I-BEAM	20 @ 20	2 x 9.33
3+940 – 5+325	PC I-BEAM	68 @ 20	2 x 12.83
	PC I-BEAM	1 @ 25	2 x 12.83
5+325 – 5+420	PC I-BEAM	30+35+30	2 x 12.83
5+420 – 8+660	PC I-BEAM	162 @ 20	2 x 12.83
8+660 – 8+690	PC I-BEAM	1 @ 30	2 x 12.83
8+690 – 9+500	PC I-BEAM	38 @ 20	2 x 12.83
9+500 – 9+970	PC I-BEAM	21 @ 20	2 x 9.33
	PC I-BEAM	2 @ 25	2 x 9.33
9+970 – 10+065	PC I-BEAM	30+35+30	2 x 9.33
10+065 – 14+000	PC I-BEAM	193 @ 20	2 x 9.33
	PC I-BEAM	3 @ 25	2 x 9.33

2. Street Overbridge

1+950	PC I-BEAM	30+30	6.00

3. Interchange Bridge

3+530	PC I-BEAM	@ 25	9.33 or 5.83

4. Pedestrian Bridge

STA. 5+400	Middle Ring Road
STA. 10+010	Phra Khanong-Bang Kapi Road
STA. 14+340	Bang Kapi-Bang Na Trad Road

9.14.2 Design of Rigid Pavement

The design method for the pavement structure for the roads was based on the TRRL ROAD NOTE 29, U.K.

(1) Average Daily Traffic

A 20-year design period from 1990 to 2010 was used for the rigid pavement design. The average daily traffic volume for each section for the selected years is as shown in Table 9–16.

TABLE 9–16 AVERAGE DAILY TRAFFIC VOLUMES FOR PAVEMENT DESIGN

Description	Average Daily Traffic Volume (veh/day)		
	1990 (open year)	2000 (10 years hence)	2010 (20 years hence)
Expressway (6-lane)	70,800	160,000	176,000
One-lane Ramp (one way)	8,900	20,000	21,000
Two-lane Ramp (one way)	22,000	39,000	51,000

(2) Equivalent Factor to Standard Axle Load (8,160 kg)

The following equivalent factors were adopted based on the study of FES, Dao Khanong-Port Section:

Heavy Vehicle	Equivalent Factor
Heavy bus	0.50
6 wheel truck	0.95
10 wheel truck	1.45

(3) Assumption for Computation

- Distribution factor
  2-lane (one way) : 0.8, 3-lane (one way) : 0.6
- Component of vehicles
  Truck (heavy): 7.9%, bus (heavy) : 5.1%

(4) Cumulative Number of Standard Axle Loads

Distributed cumulative number of standard axle loads is computed as shown below:

Description	Distributed Cumulative Number
Expressway	37.3×10^6
One Lane Ramp	15.4×10^6
Two Lane Ramp	26.5×10^6

(5) Determination of Pavement Slab Thickness

The thickness of concrete pavement slab was determined based on the used of design chart shown in Fig. 11 of the Road Note 29.

The pavement structure resulting from this procedure is as follows when the design CBR of sub-grade adopted for pavement is 2%:

	Expressway	Ramp (1-lane) (2-lane)
PORTLAND CEMENT CONCRETE (CM.)	26 CM.	24 CM.
SUB-BASE (CM.)	15 CM.	15 CM.
TOP OF EARTHWORK (SUBGRADE)		

9.15 Soils and Materials Study

9.15.1 Engineering Geology of the Project Area

In the project area, the alluvial and marine deposits extend to an indeterminate depth of not less than 300 meters. It is thought that the greatest part of those deposits have been laid in the quaternary and recent times and are sands of alluvial origin. However, the upper 15 to 20 meters part of the infilling consists of clays mainly of marine origin. It has been postulated that about 20,000 years ago the rate of depression of the basin exceeded the rate of deposition of the Chaophraya River and the land was thus inundated by the sea possibly as far north as Uttaradit.

The marine clays appear to have been deposited between 8,000 and 4,000 years ago. With the combined effects of tides and deposition of alluvial clay and silts from the Chaophraya River in flood, the shoreline was gradually extended southwards and the land emerged above the mean sea level. This process of deposition is still continuing with the present shoreline developing southwards at 4–5 meters per year.

The marine and alluvial deposits accumulated in the above manner have formed an exceptionally homogeneous and level plain. The elevation at Chai Nat is +18 meters, that at Ayutthaya +4 meters and that of Bangkok being only +1 to +2 meters above mean sea level. A longitudinal section through the basins from north to south is shown in Fig. 9–16.

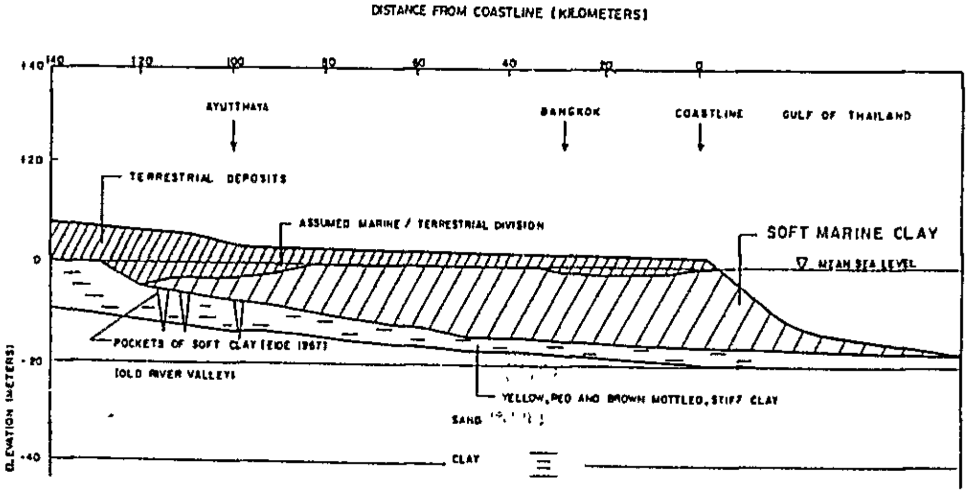


FIG. 9–16 LONGITUDINAL SOIL PROFILE

The deposits found in the Bangkok area are fairly consistent and generally conform to the following sequence:

- A weathered crust about 2 meters thick and composed of mottled grey-brown clay having cracks due to the cycles of wetting and drying;
- Very soft to medium dark grey clay referred to as soft Bankok clay typically 10–15 meters thick;
- Stiff to hard grey and yellow brown clay of variable thickness; and
- Dense sand and general layers with some sandy clay. Those layers occuring alternately to an indeterminate depth.

Variations from the above sequence should be expected especially in close proximity to river channels.

The geological history of the deposits would indicate that clays should be normally consolidated, and this is generally the case with the soft Bangkok Clays. However, the stiff to hard clays generally exhibit the characteristics of an over-consolidated clay. In the absence of any evidence of over-consolidation it is generally accepted that these properties result from desication.

9.15.2 Soils and Materials Survey

(1) Purpose of the Survey

The purpose of the survey is to obtain the necessary data for the design of the soft ground treatment, embankment, pavement and structures with the data to supplement the past surveys which were carried out by others.

(2) Analysis of Existing Data

As beforementioned the sub-soils in the Bankok area are fairly homegeneous and there are a large amount of published data. Therefore, representative strata and soils characteristics were initially identified from the following data:

- First Stage Mass Transit System in Bangkok, Factual Report on Soil Investigation, October 1980;
- The Nonthaburi & Pathumthani Bridges Construction Project, Geothechnical Report, August 1980, and Soil Material and Hydaulics Reports, November 1980;
- Memorial Bridge-II Prlject, New Bridge Preliminary Design, July 1979;
- Feasibility Report on Bangkok-Thonburi Bridge No. 1 Project, October 1968;
- Feasibility Study for the Outer Bangkok Ring Road, Final Report, Volume 3: Appendices, December 1978; and
- Bang Sue Container Freight Station, Geotechnical and Soils Evaluation, April 1983.

Among others, in the inception route study, data from the above First Stage Mass Transit System in Bangkok were much referred to as a guide of preparation of the soil profiles.

(3) Field Work and Laboratory Testing

The field work and laboratory testing was executed by a local consulting firm, National Engineering Consultants, Bangkok. The Study Team planned the field work and laboratory tests.

The summary of items of soils and materials survey conducted, is shown in Table 9–17 (Please see Fig. 9–17 for the location of boreholes).

9.15.3 Description of Sub-Surface Soils along the Proposed Expressway Routes

Details of Sub-surface conditions along the N–S Route and East Route are seen in the Figs. 9–18 and 9–19. The bearing strata suitable as pile foundation is situated at a depth of between 20 meters and 30 meters.

Properties of the crust, soft to stiff clays and dense sand layers are described below, based on the data obtained by the survey and on other published data. Their typical properties are shown in Table 9–18.

TABLE 9–17 SUMMARY OF ITEMS OF SOILS SURVEY

	Item	Unit	Quantity
a.	Field Works including		
	Machine Boring, for unclassified Soils	meter	160
	Standard Penetration Test	each	80
	Thin-Walled Tube Sampling	each	24
	Dutch Cone Penetration Test	meter	120
b.	Laboratory Test		
	Testing for the Soils taken by Split Sampler	each	24
	Testing for the Soils taken by Thin-Walled Tube (including Consolidation Test)	each	24
	Laboratory Test of Embankment Materials from Borrow Pit (including Sampling)	each	3
	Laboratory Test of Fill Materials available at the Site (including Sampling)	each	10

The underlying sands are characterized by Standard Penetration N-values ranging from 15 to 30 fot the top 2 meters but generally greater than 50 beyond this depth.

(1) Weathered Clay Top Layer

The uppermost layer of 0.5 to 3 meters is grey-brown clay and forming a weathered "dry crust" and a partial fill of various materials. The formation is normally consolidated to slightly over-consolidated clay.

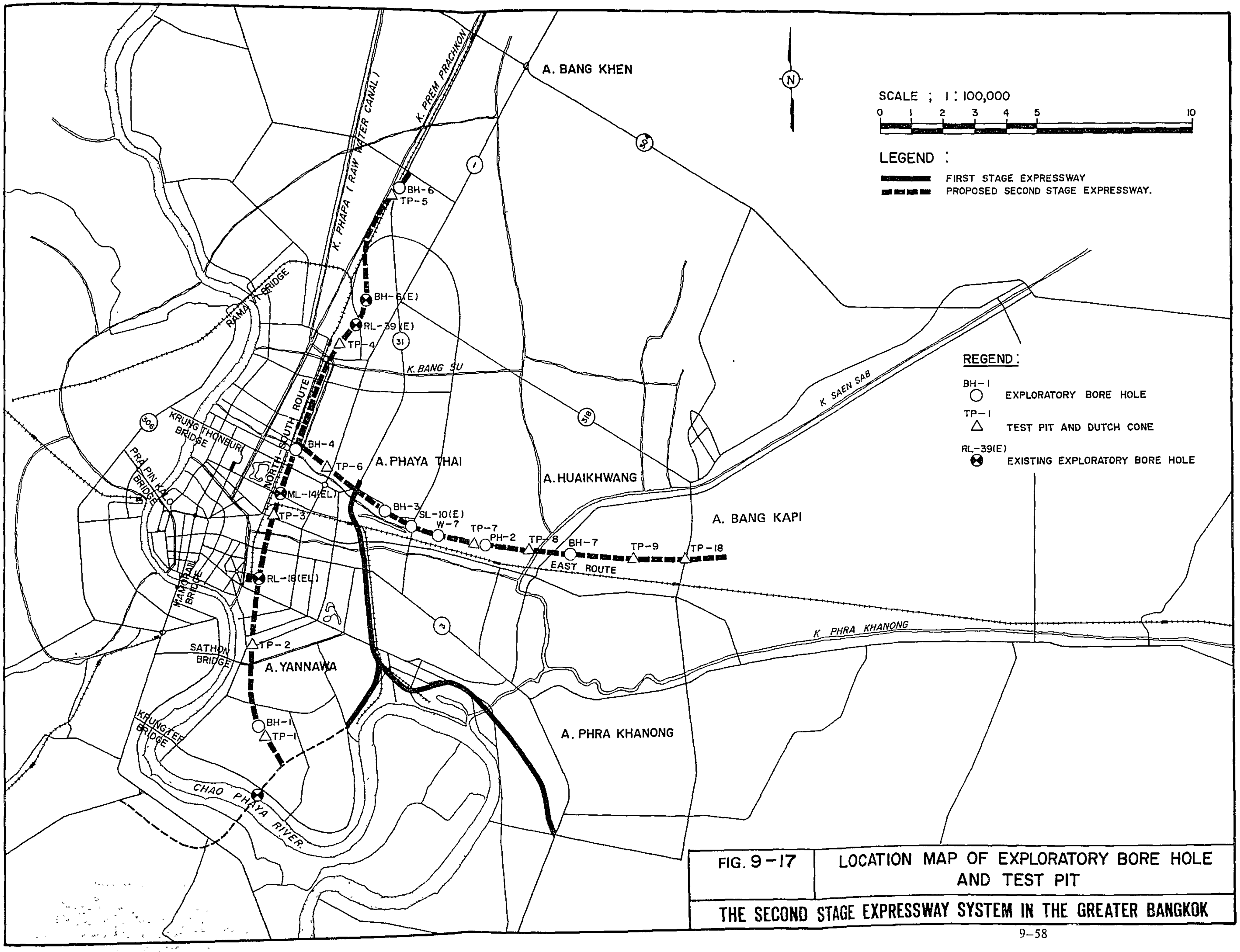
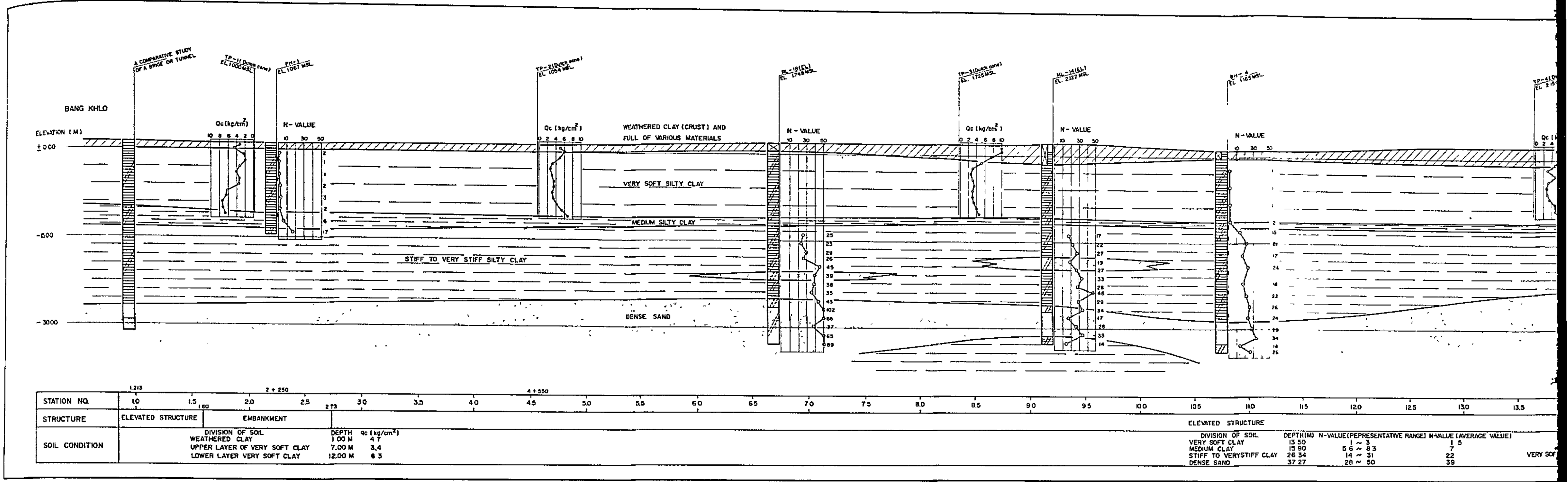


FIG. 9-17 LOCATION MAP OF EXPLORATORY BORE HOLE AND TEST PIT

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK


BANG KHLO
ELEVATION (M)
±0.00
-15.00
-30.00
A COMPARATIVE STUDY OF A BRIGE OR TUNNEL
Qc (kg/cm²)
N - VALUE
WEATHERED CLAY (CRUST) AND FULL OF VARIOUS MATERIALS
VERY SOFT SILTY CLAY
MEDIUM SILTY CLAY
STIFF TO VERY STIFF SILTY CLAY
DENSE SAND
STATION NO.
STRUCTURE
SOIL CONDITION
ELEVATED STRUCTURE
EMBANKMENT
DIVISION OF SOIL
WEATHERED CLAY
UPPER LAYER OF VERY SOFT CLAY
LOWER LAYER VERY SOFT CLAY
DEPTH
1.00 M
7.00 M
12.00 M
ELEVATED STRUCTURE
VERY SOFT CLAY
MEDIUM CLAY
STIFF TO VERYSTIFF CLAY
DENSE SAND

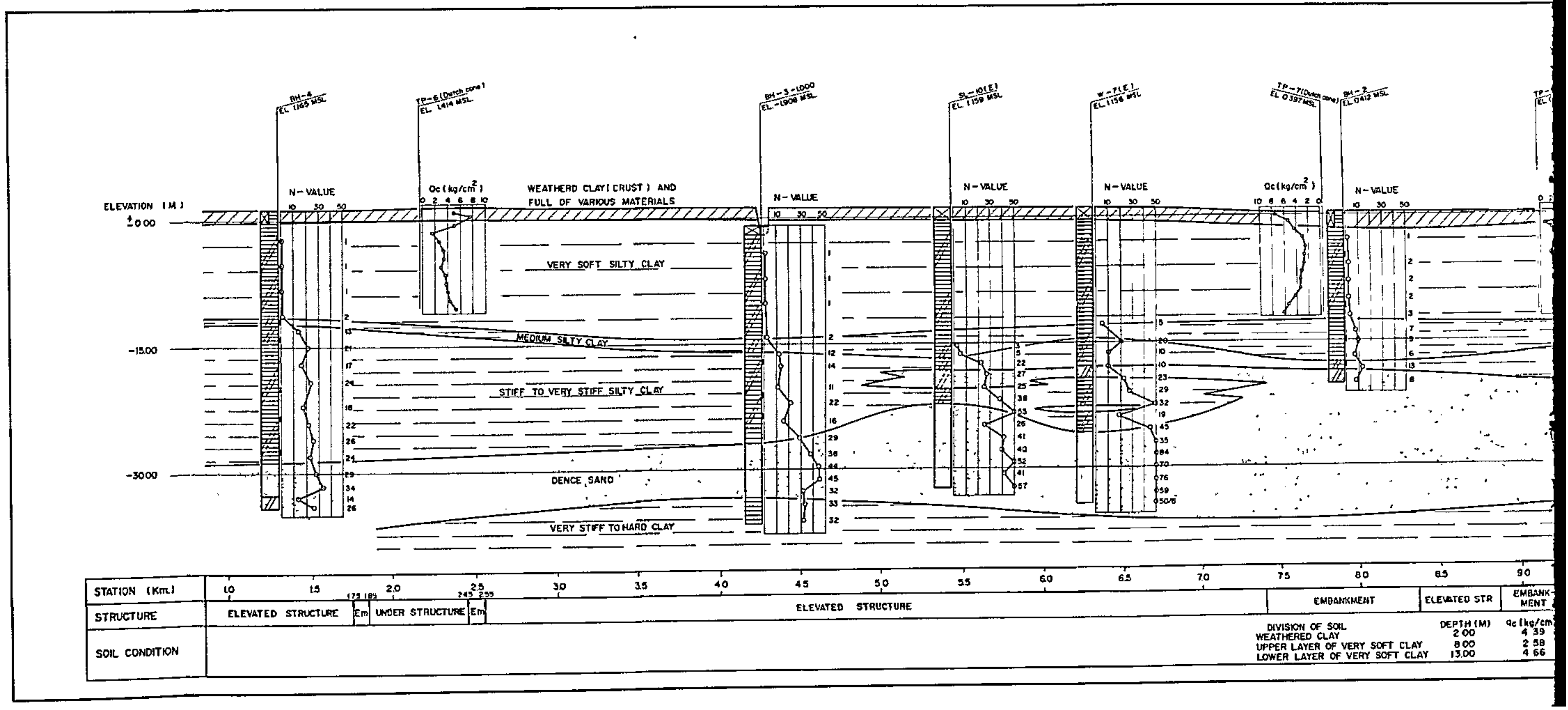
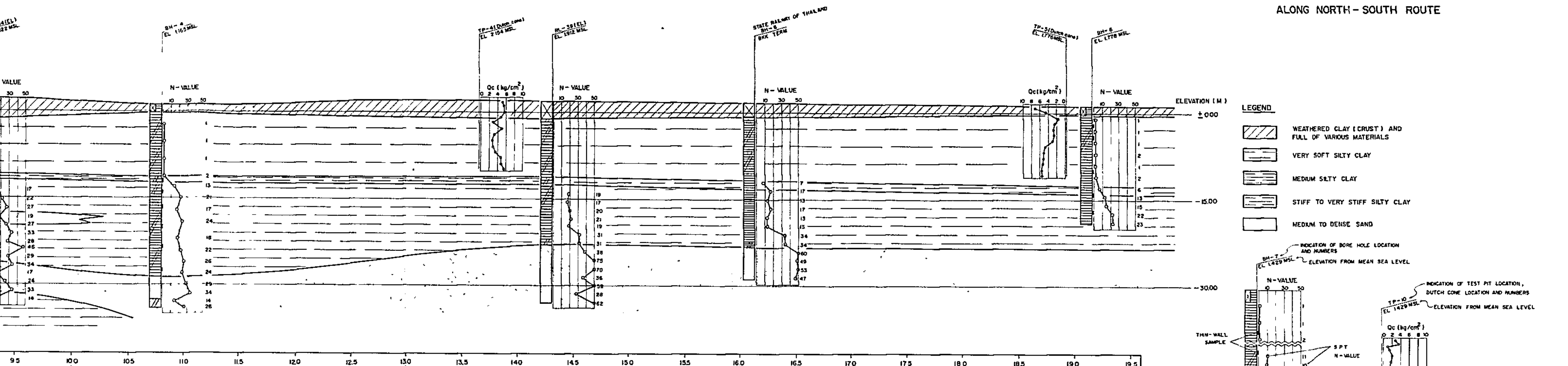

ELEVATION (M)
±0.00
-15.00
-30.00
N - VALUE
Qc (kg/cm²)
WEATHERD CLAY (CRUST) AND FULL OF VARIOUS MATERIALS
VERY SOFT SILTY CLAY
MEDIUM SILTY CLAY
STIFF TO VERY STIFF SILTY CLAY
DENCE SAND
VERY STIFF TO HARD CLAY
STATION (Km.)
STRUCTURE
SOIL CONDITION
ELEVATED STRUCTURE
UNDER STRUCTURE
ELEVATED STRUCTURE
EMBANKMENT
ELEVATED STR
DIVISION OF SOIL
WEATHERED CLAY
UPPER LAYER OF VERY SOFT CLAY
LOWER LAYER OF VERY SOFT CLAY
DEPTH (M)
2.00
8.00
13.00

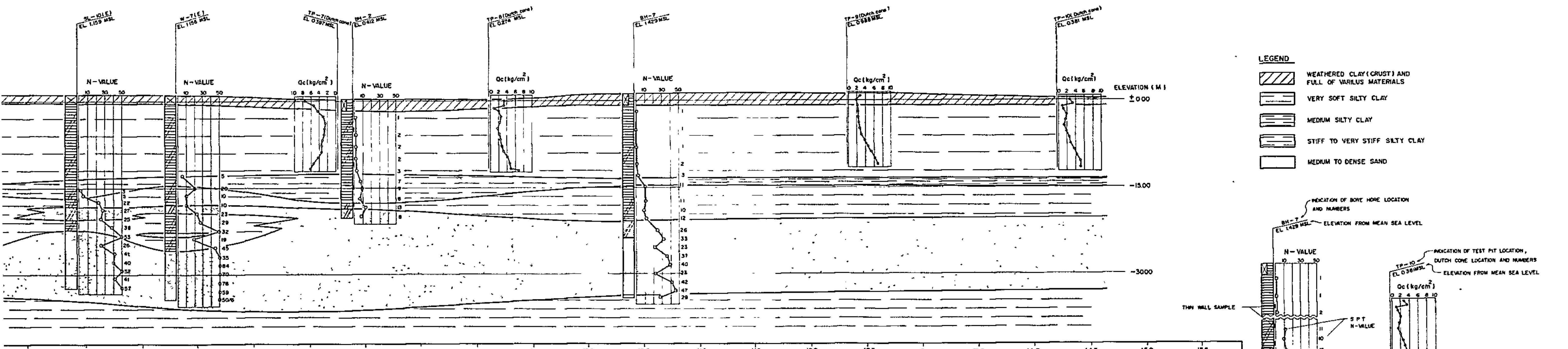
FIG 9-18 LONGITUDINAL SOIL PROFILE
ALONG NORTH-SOUTH ROUTE



DIVISION OF SOIL	DEPTH(M)	N-VALUE(REPRESENTATIVE RANGE)	N-VALUE (AVERAGE VALUE)
VERY SOFT CLAY	13 50	1 ~ 3	1 5
MEDIUM CLAY	15 90	5 6 ~ 8.3	7
STIFF TO VERYSTIFF CLAY	26 34	14 ~ 31	22
DENSE SAND	37 27	28 ~ 50	39

DIVISION OF SOIL		DEPTH(m)	qc(REPRESENTATIVE RANGE)	qc(AVERAGE VALUE)
VERY SOFT CLAY	WEATHERED CLAY	1 8	2 6 ~ 7.6 kg/cm²	5.1 kg/cm²
	UPPER LAYER	8 7	2.1 ~ 3 7 "	2 9 "
	LOWER LAYER	13 5	4 2 ~ 6.2 "	5.2 "

FIG. 9-19 LONGITUDINAL SOIL PROFILE
ALONG EAST ROUTE



DIVISION OF SOIL	DEPTH (M)	qc(kg/cm²)
WEATHERED CLAY	2.00	4.39
UPPER LAYER OF VERY SOFT CLAY	8 00	2.58
LOWER LAYER OF VERY SOFT CLAY	13.00	4 66

DIVISION OF SOIL	DEPTH(M)	N-VALUE(REPRESENTATIVE RANGE)	N-VALUE(AVERAGE VALUE)
VERY SOFT CLAY	13 50	1 ~ 3	1 5
MEDIUM CLAY	15 90	5 6 ~ 8 3	7
STIFF TO VERY STIFF CLAY	26 34	14 ~ 31	22
DENSE SAND	37 27	28 ~ 50	39

DIVISION OF SOIL		DEPTH(m)	qc(REPRESENTATIVE RANGE)	qc(AVERGE VALUE)
VERY SOFT CLAY	WEATHERED CLAY	1 8	2 6 ~ 7 6 kg/cm²	5 1 kg/cm²
	UPPER LAYER	8 7	2 1 ~ 3 7 "	2.9 "
	LOWER LAYER	13.5	4 2 ~ 6 2 "	5 2 "

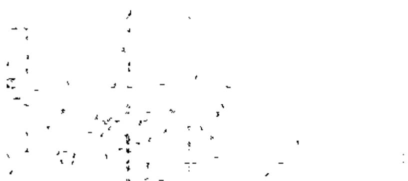


TABLE 9–18 TYPICAL PROPERTIES OF SUB-SURFACE SOILS

Item of Soils properties \ Strata		Very soft clay (Soft BKK clay) Represent-ive Range	Very soft clay (Soft BKK clay) Average Value	Stiff to very Stiff clay Represent-ive Range	Stiff to very Stiff clay Average Value	Dense Sand Represent-ive Range	Dense Sand Average Value
Gradation	Gravel (%)	-		0∿1.4	0.4	0∿8.6	1.9
Gradation	Sand (%)	0.7∿31.0	7.6	0.5∿12.7	4.9	55.4∿90.5	79.4
Gradation	Silt (%)	16.2∿45.7	28.9	12.4∿42.7	27.2	5.8∿21.2	12.8
Gradation	Clay (%)	39.0∿83.0	63.5	47.0∿83.0	67.5	0∿25.0	5.9
Consistency	Liquid limit W_L (%)	58.9∿87.7	73.3	41.1∿74.2	57.6	-	-
Consistency	Plastic limit Wp (%)	26.5∿35.8	30.9	18.0∿27.8	22.9	-	-
Consistency	Plasticity Index Ip	30.5∿54.3	42.4	22.1∿47.1	34.6	-	-
Specific Gravity of Soil Gs		2.521 ∿ 2.597	2.559	2.525 ∿ 2.607	2.566	2.570 ∿ 2.680	2.625
Natural state	Water content Wn (%)	59.0∿84.2	71.6	20.4∿33.8	27.1	15.5∿23.7	19.6
Natural state	Wet unit γt (t/m^3)	1.551 ∿ 1.635	1.593	1.886 ∿ 2.109	1.997	-	-
Natural state	Void Ratio e	1.486 ∿ 2.014	1.750	0.482 ∿ 0.811	0.647	-	-
Unconfined Compression	Compressive strength qu (kg/cm^2)	0.269 ∿ 0.483	0.376	1.085 ∿ 2.061	1.573	-	-
Unconfined Compression	Modulus of Elasticity E50 (kg/cm^2)	12.0 ∿29.5	20.7	61.3 ∿149.7	100.5	-	-
Consolidation	Yeild stress of Consolidation Py (kg/cm^2)	0.59 ∿0.91	0.75	2.16 ∿4.36	3.26	-	-
Consolidation	Compression indx Cc	0.64∿1.10	0.87	0.13∿0.41	0.26	-	-
Classification	Visual classification	CL ∿ CH		CL ∿ CH		SM ∿ SP	
Classification	Unified classification	CH		CL ∿ CH		SP	
Field test	N-value	1∿3	1.5	Stiff to very stiff clay 14∿31	22.4	28∿50	39
Field test	N-value			Upper zone (Medium clay) 5.6∿8.3	6.9		
Field test	Detch cone qc (kg/cm^2)	Weathered clay (crust)					
Field test	Detch cone qc (kg/cm^2)	2.6∿7.6	5.1	—		—	
Field test	Detch cone qc (kg/cm^2)	Upper zone					
Field test	Detch cone qc (kg/cm^2)	2.1∿3.7	2.9	—		—	
Field test	Detch cone qc (kg/cm^2)	Lower zone					
Field test	Detch cone qc (kg/cm^2)	4.2∿6.2	5.2	—		—	
Remark							

(2) Soft Bangkok Clay

Very soft to medium dark grey silty clays, reaching depths generally between 10 and 20 meters, are recent and highly compressible.

(3) Stiff to Hard Clay

Stiff to hard grey and yellow-brown clay lie underneath soft Bangkok clay. The depth of this formation is generally between 13.5 to 30.0 meters and their thickness is 11.8 to 15.5 meters.

(4) Dense Sand Layers

Dense sand layers are light brown to greyish-brown fine to medium sand with some sandy clay. Their formation is underneath stiff to hard clay. Their formation is underneath stiff to hard clay and generally their depths are from 19.0 to 37.0 meters. The upper layer is 2 to 3 meters thick and their N-values range from 8 to 9. The N-values of lower layers are from 28 to 50.

9.15.4 Materials Sources

Based on the results of the study of available materials data as well as the factual test results obtained by the materials survey, comments on each of the main materials are given below (see Table 9–19 for Typical properties of Materials).

TABLE 9–19 TYPICAL PROPERTIES OF MATERIALS

Materials / Item of Materials Properties		Weathered Clay (crust)		Laterite		Sand	
		Representive Range	Average Value	Representive Range	Average Value	Representive Range	Average Value
Gradation No. 200 sieve passing (%)		90.6∿98.1	94.3	14.5∿11.7	13.1	0.2∿0.5	0.35
Specific gravity		2.503 ∿ 2.563	2.533	2.610 ∿ 2.730	2.670	2.61∿2.66	2.635
Consistency	Liquid limit (%)	47.6∿58.8	53.2	–	25.1	-	-
	Plastic limit (%)	23.7∿25.7	24.7	–	15.3	-	-
	Plasticity index	23.4∿33.6	28.5	–	9.8	-	-
Unified soil Classification		CL ∿ CH		CL		SP	
Compaction T180	Optimum water Content (%)	14.6∿19.4	17.0	6.3∿9.3	7.8	-	14.0
	Maximum Dry Density (t/m³)	1.697 ∿ 1.771	1.734	2.150 ∿ 2.230	2.190	-	1.650
California bearing Ratio (CBR) Modified CBR, Soaked (%)		1.0∿3.1	2.1	-	27.0	–	28.5
Remark		o Weathered clays (crust) are Laboratory tests results of TP-1 ∿ TP-10. o Laterite is produced at Phetchaburi o The sources of sand produced as old river deposit					

The main rock sources are located near Saraburi and Ratchaburi, almost all the rock obtained for commercial use is limestone although some rhyolite is available from the Saraburi area.

Information on rock sources is summarized as shown in Table 9–20.

TABLE 9–20 MAIN ROCK SOURCES

Kind of Rock	Production Site	Approximate Distance from Site (km)	Remarks
Limestone	Ratchaburi	106 – 119	Ratchaburi Formation (Carboniferous and Permian)
Shale, Sandstone, Sandy Shale	Othong	100 – 133	Kanchanaburi Formation (Carboniferous Silurian)
Limestone (with Shale, Sandstone Conglomerate)	Lopburi	137 – 159	Ratchburi Formation (Carboniferous Permian)
Ryolite	Saraburi	106 – 115	Pre-Triassic
Granite	Cholburi	89 – 104	(Carboniferous)

In view of the number of rock sources available and the general quality of the stone there should be no problems in obtaining rock suitable for concrete works, aggregate base, asphaltic concrete and surface tratment.

(1) Sand

The high demand for sand in the Bangkok area has resulted in many traditional sand sources being worked out and new sources have only been found at considerable distances from Bangkok.

The bulk of fine sand suitable only for use in embankment works now comes from Kamphaeng Saen whereas the main sources for sand suitable for concrete works are located in the Kanchanaburi and Ratchaburi areas. Even here the quality of the sand from the Mae Khlong River is quickly deteriorating as the coarser deposits are being worked out.

Main sources of sand are tabulated as shown in Table 9–21.

TABLE 9–21 MAIN SOURCES OF SAND

Production Site	Approximate Distance from Site (km)	Remarks
Ayutthaya	68 – 119	Old river deposit
Kanchanaburi Ratchaburi	96 – 119	Old river deposit and terrace
Cholburi	89 – 107	Marine sand and terrace

Coarse sand suitable for high quality concrete production is obtainable but frequent checks on the grading and quality together with required processing must be made. The sources produce sand by dredging without screening or washing so that the grading may change from day to day as the river level fluctuates.

(2) Laterite

Sources of laterite are located in the Saraburi, Kanchanaburi and the Ratchaburi areas, however, the quality of the material shows considerable variation. Main sources of laterite are shown in Table 9–22.

TABLE 9–22 MAIN SOURCES OF LATERITE

Production Site	Approximate Distance from Site (km)	Remarks
Ratchaburi	104 – 126	Borrow pits in piedmont
Kanchanaburi	130 – 167	– ditto –
Saraburi	118 – 148	– ditto –
Prachinburi	122	– ditto –

(4) Manufactured Products

A wide range of materials and manufacturing facilities are obtainable locally, the following are freely available in sizes/grades suitable for use:

- Cement;
- Bitumen;
- Plain and deformed reinforcing bar;
- Prestressing strand in a limited range of sizes;
- Prestressing wire;
- Prestressed concrete beams;
- Prestressed concrete piles; and
- Concrete culvert piles.

A wide range of fabricated steel products may be made locally althrough steel structural sections and steel plate must be imported.

9.15.5 Foundation Studies

(1) Driven Piles (Precast Concrete Piles)

Pre-stressed concrete piles are widely available in the Bangkok area and this type of pile probably represents the most satisfactory solution for the foundations of the approach spans and flyovers or viaducts.

(2) Embankment Study

It is clear that as the embankment height is increased the factors of safety against stability are reduced and the settlenents are increased, there are therefore advantages in having minimum embankment heights.

However, much of the low lying ground in the project area is liable to flooding during the wet season and to prevent inundation of the at-grade Expressway, with the resulting disruption to traffic and damage to the pavement, it is necessary to construct the embankments to a sufficient height above the flood level.

In the soft Bangkok clays, consolidation settlements may take place for several years after construction and secondary plastic settlements may continue at a fairly uniform rate over long periods.

a) Stability

The factors of safety of embankments of various heights were calculated using a computer program based on the following criteria:

- A total stress analysis using the unconfined compression strengths of the clay layers. All possible radii and centres of relevant slip circles are considered at 1 meter intervals; and
- The embankment is assumed to be cracked due to plastic movements and therefore has zero shear strength. Cracks are assumed to be vertical.

The plots of embankment height against factor of safety are shown in Fig. 9–20.

In view of the above it may be assumed that embankments up to 2 meters high are satisfactory from stability considerations without a toe berm.

b) Settlements

Although laboratory tests give a reasonable guide to total consolidation settlements there are problems in estimating the times over which these settlenents occur. The situation is further complicated by plastic flow in the soft clays and secondary settlements which are not predicted by laboratory tests.

The initial step taken in calculating settlements was to determine the stresses at various depths caused by the superimposed embankment loads. This calculation was made by dividing the embankment into a number of strips and summing the stresses at any point due to each strip. The stresses were computed in accordance with the Bousinnesque equations. Although these equations make a number of simplifying assumptions with regard to the soil properties they generally give a reasonable estimation of vertical stress.

In calculating the settlements due to primary consolidation we utilised the average consolidation curves in conjunction with the plots of vertical stress to determine the settlement at various points below the embankments. The resulting settlements for 1.45 meter and 2.65 meter high embankments are shown in Fig. 9–21.

It should be emphasised that these settlements are primary consolidation settlements which will occur over the period of excess pore pressure dissipation, secondary settlements due to creep or other factors will be additional to these settlements.

c) Differential Settlements

Road embankments constructed on soft Bangkok clays are subject to considerable settlement. If this settlement is uniform over the length of the embankment relatively little damage is caused to the pavement and the riding quality of the surface is maintained.

However, if large differential settlements occur between different parts of the embankment the pavement may be seriously damaged. Differential settlements

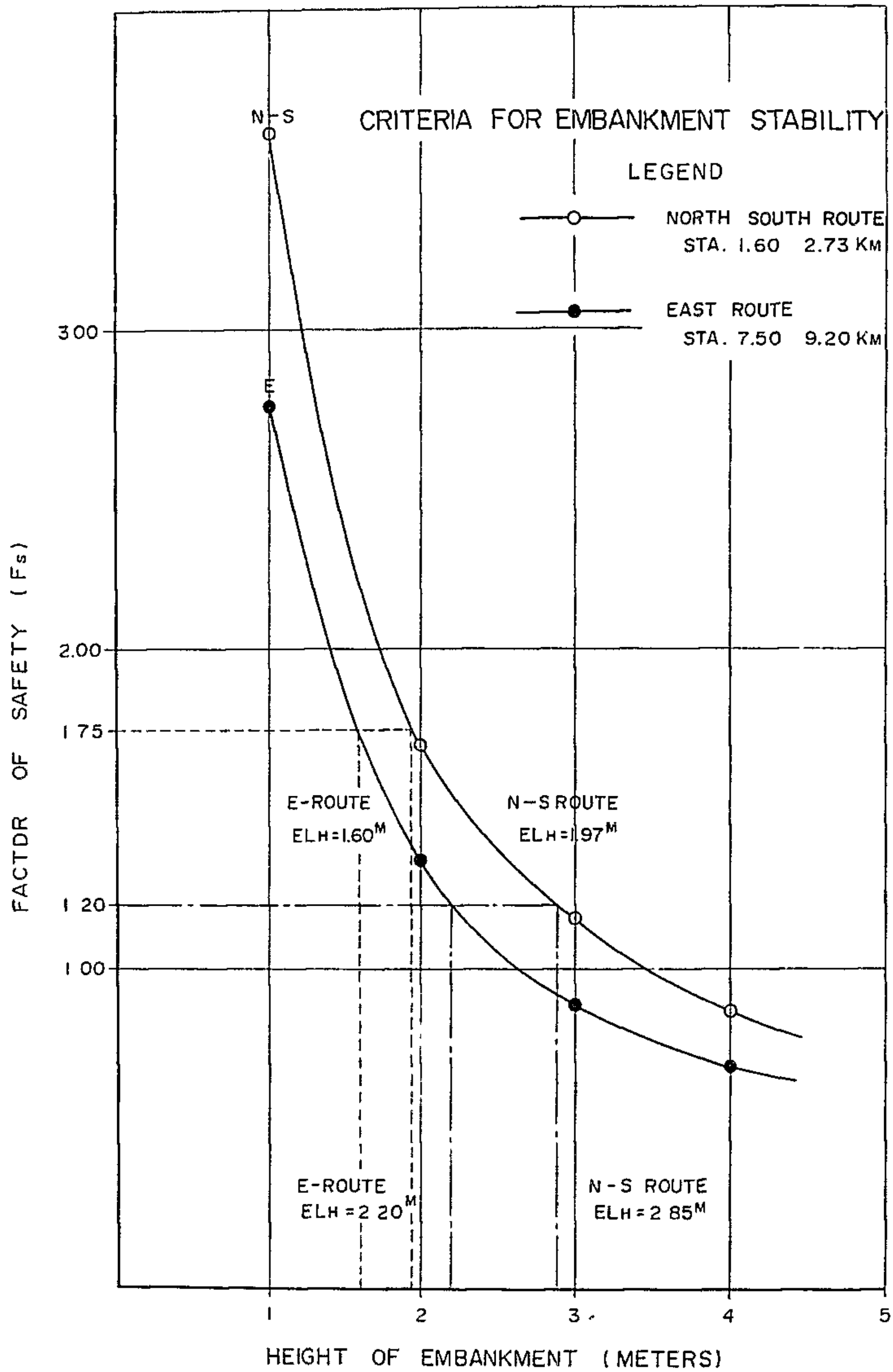


FIG. 9-20 EMBANKMENT HEIGHT AND FACTOR OF SAFETY

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

are most likely to occur at points where the embankment connects to a rigid structure.

After consideration of the various methods available for reducing the effects of differential settlements it was decided that piles approach slabs should prove most effective in reducing the effects of differntial settlenents. These must therefore be provided at each structure.

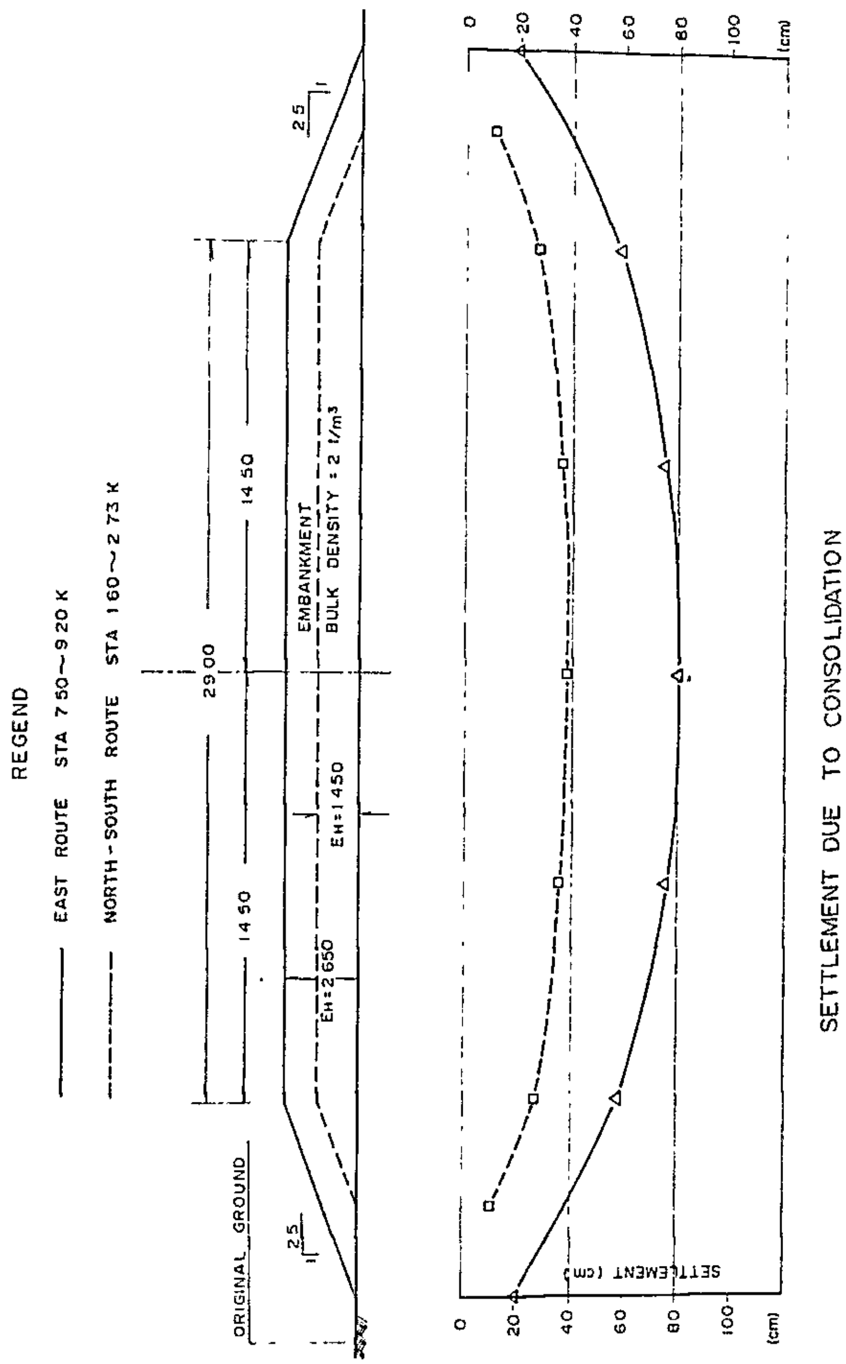


FIG. 9–21 SETTLEMENT DUE TO CONSOLIDATION

9.16 Hydrological Study

9.16.1 Study Purpose

The study was carried out to furnish the data, from a hydrological and hydraulic point of view, for the design for the bridges and drainage structures, and to determine the lowest safe finished grade in the embankment sections at river basins so that the profiles of the Expressway could be planned avoiding flood problems.

9.16.2 Site Surveys

To learn more about the existing hydrological data, the characteristics of the relevant areas were investigated carefully and the data obtained was studied to prepare the proper bases for the preliminary engineering design. Fig. 9–22 shows the existing situation of the project area.

9.16.3 Meteorology

Three major wind systems have been identified:

- NE monsoon (late October – mid February, cool season);
- NE to SW wind (mid February – mid May, hot season); and
- SW Monsoon (mid May - mid October, rainy season).

The mean annual rainfall observed in GBA is 1,464 mm. Since the area has a tropical heavy rainfall, the type of rainfall is characterized by heavy showers.

The annual mean temperature in Bangkok is 28°C and the hottest month is May (with the mean temperature of 35°C).

9.16.4 General View of Existing Drainage Environment

(1) Chaophraya River

The river basin of the Chaophraya comprises most of the mountainous areas and valleys in Northern Thailand and Central Valley. It extends from the Thai-Burma border in the north down to the Gulf of Thailand in the south, with the whole catchment area of roughly 177,550 km^2, or about 31% of the total area of the Kingdom. In the southern part of the basin, a vast alluvial plain called Bangkok Plain, is developed with the results of soil sedimentation and deposition by the Chaophraya River. The Bangkok Plain is dissected by numberous canals and drainage courses which irrigate and drain the vast area developed for rice cultivation.

Land gradients are extremely flat in the delta region and the area is covered with an impermeable and deep layer of clay. The altitudes of the lowest and highest lands do not differ by more than about one meter and the mean land elevation in Bangkok Metropolitan Area is 1.5 meter above M.S.L. Therefore, at the end of the rainy season, the rainfall and the high water of the Chaophraya River cause floods frequently about 50 cm above the surface of the land.

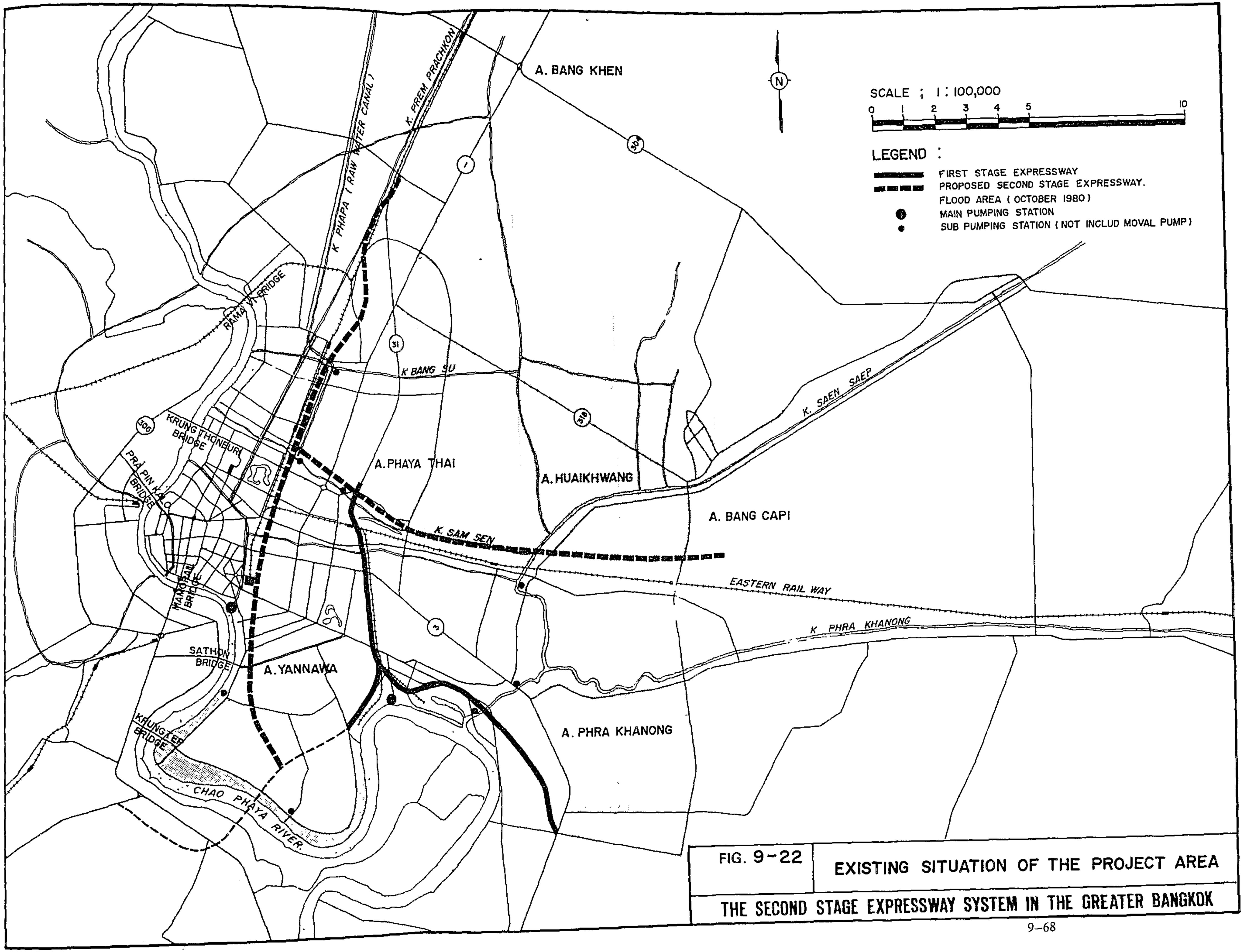


FIG. 9-22 EXISTING SITUATION OF THE PROJECT AREA

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK

(2) Drainage Situation of the Greater Bangkok Area

There are several main canals in GBA for the purposes of urban drainage, irrigation, and waterborne traffic. To supply the water from the Chaophraya River to Bangkok, a raw water intake canal which is called Khlong Prapa exists along the Rama VI Road under the control of MWWA.

Usually the canals that have developed in a very flat alluvial area connecting to the tidal river have a low hydraulic gradient of nearly 1/100,000 – 1/50,000.

In view of the existing canal conditions and rapid urbanization, a master plan was prepared by Camp Dresser & McKee in 1968 for the sewerage, drainage and flood-prevention systems. In order to establish a more comprehensive program for the drainage and flood-prevention throughout the whole metropolis, the revision of master plan is undergoing by BMA for more relevant system under the cooperation of DOH and RID.

(3) Recent Flood Occurred in the Greater Bangkok Area

The remarkable floods in the Greater Bangkok Area occurred in 1964. 1975, 1978 and 1980, as shown in Table 9–23.

TABLE 9–23 RECORD OF THE RECENT FLOOD IN GBA

Year	Month	Max. Water Surface Level (m)	Monthly Rainfall (mm)	Max. Daily Rainfall (mm)	Max. Hourly Rainfall (mm)
1964	Sept.	+1.20	402.9	114.9	28.5
	Oct.	+1.68	100.2	-	18.1
	Nov.	+1.74	10.0	-	5.7
1975	Sept.	+1.46	211.5	68.3	37.2
	Oct.	+1.78	261.5	-	41.3
	Nov.	+1.99	35.0	-	16.4
1978	Sept.	+1.44	274.7	-	32.8
	Oct.	+1.99	102.5	34.0	30.7
	Nov.	+1.86	0.6	-	0.6
1980	Sept.	+1.58	352.3	-	42.1
	Oct.	+1.85	324.5	84.1	54.9
	Nov.	+1.92	33.9	-	9.4

Notes: 1. Rainfall recorded at Bangkok Metropolis, Station 48455.
2. Maximum water surface level recorded at the Memorial Bridge.

Among the above recorded flood, the one occurred in 1975 was most serious and occupied a number of large areas of the GBA for the period of about 2 months.

The main factors of the occurrence of the floods in GBA are to be considered among others, as follows:

- The discharge through the Chaophraya River;
- The high tide of the Gulf of Thailand;

- Local precipation with high intensity;
- Influence of the backwater of the Chaophraya River;
- Decreased flood storage basin and increased run-off coefficient due to the rapid urbanization;
- Insufficient capacities of the existing drainage canals.

9.16.5 Rainfall

(1) General

A number of rainfall observation stations exist in the BMA and have been in systematic operation since 1951.

The rainfall distribution of the area is under the influence of the seasonal direction of monsoon. The rainy season prevails from mid-May to mid-October as the southwest monsoon brings a moist air from the Indian Ocean. The highest rainfall usually occurs in September.

In addition, tropical storms and tropical depressions reach the Gulf of Thailand in August, September and October. However, the rainfall directly associated with these storms has much less intensity than the rainfall associated with the southwest monsoon.

(2) Rainfall Intensity-Duration-Frequency Curves for Short Durations of Rainfall

The rainfall intensity-duration-frequency curves for the drainage study were obtained from DOH and shown in Fig. 9–23. These curves were adopted for shorter durations of the rainfall of less than two hours.

(3) Rainfall Intensity-Duration-Frequency Curves for Long Durations of Rainfall

The annual daily and hourly maximum rainfall records during the period of 1951–1981 at Bangkok Metropolis Station were collected to study longer durations of rainfall.

For longer durations of the rainfall, the rainfall intensities were deduced based on the probability density function (PDF). Table 9-24 shows the rainfall probability for the various terms of the period.

TABLE 9–24 RAINFALL PROBABILITY

Return Period (Year)	Daily Rainfall (mm)	Hourly Rainfall (mm)
5	116.0	73.8
10	134.4	86.1
20	151.8	98.2
25	157.0	101.5
50	174.0	113.5
100	190.6	124.9

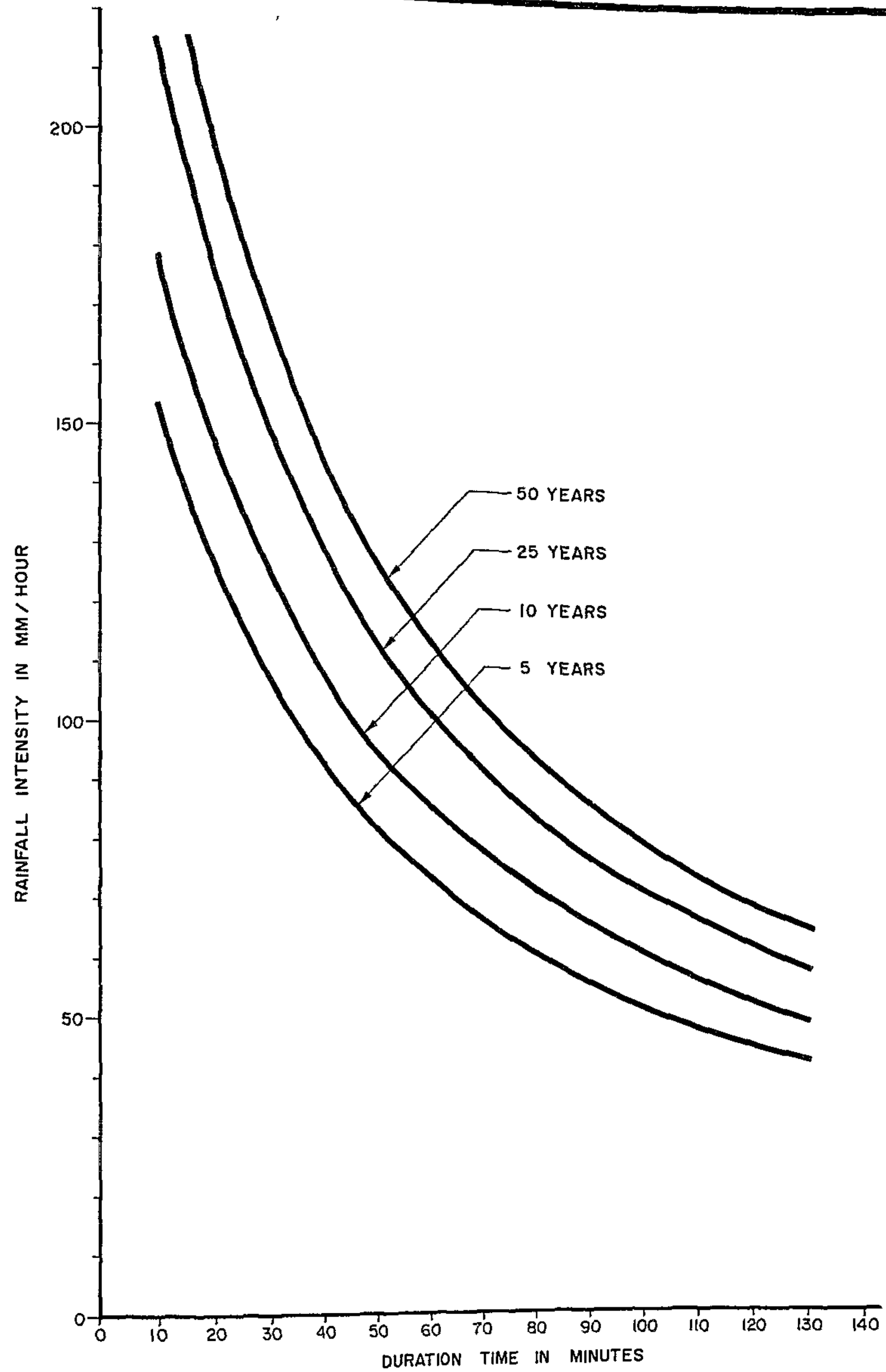


FIG. 9-23	INTENSITY - DURATION - FREQUENCY CURUE IN BANGKOK METROPOLIS

THE SECOND STAGE EXPRESSWAY SYSTEM IN THE GREATER BANGKOK