# REPORT ON STUDY FOR ELECTRIFICATION OF THE PNR COMMUTER SERVICE

December 1978

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

# P R E F A C E

In response to a request by the Government of the Philippines, the Government of Japan decided to take up a study on the Electrification Project planned by the Philippine National Railways to replace the present diesel trains in order to cope with the increasing demand of commuters in the Manila area and the Japan International Cooperation Agency carried out the study.

Noting that the project has a vital bearing on the development and lives of the inhabitants in the densely populated Manila area, the Agency dispatched a study team consisted of 2 experts from February 2 to May 1, 1978.

The study team held discussions on the project with the Philippines Authorities concerned, collected information and data and conducted a field survey necessary for planning the electrification. Based on the field survey, and taking account of advice and views offered by the competent Authorities of various Departments of the Philippines Government, the team has compiled this report.

I sincerely hope that this report will contribute to the socio-economic development in the Manila area and to the enhancement of the friendly relations between our two countries.

I would like to take this opportunity to express my heartfelt appreciation to all the people concerned in the Philippines for their whole-hearted assistance extended to the study team.

December 1978

Shinsaku Hogen
President
JAPAN INTERNATIONAL COOPERATION AGENCY

# EXPERTS DISPATCHED

| Name | Assignment | Occupation |
| --- | --- | --- |
| Yasuo Sato | Roadway | Assistant Head<br>Track Maintenance Section<br>Facilities Bureau<br>Japan National Railways |
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# SUMMARY

1. The PNR Commuter Service will go a long way toward solving traffic problems in Metro Manila.

2. PNR is obliged to improve the reliability and punctuality of the operating schedules.

3. The electric car traction is advantageous in many respects over the diesel car traction. A few of them are cited below.

   (1) Reduced transport cost

   (2) Increase in speed and transport capacity

   (3) Improved transport service

   (4) Energy-saving

4. Results of economic comparison study of electric car traction and diesel car traction

   The cases in which the electrification will get the better of diesel scheme are as follows.

   Each case is given some latitude, because the get-out point is a function of prime rate and the number of diesel cars purchased before electrification.

   (1) Case 1 (where the diesel car maintenance cost is calculated according to PNR's empirical data)

   Where the number of trains per day per line becomes in excess of 30 to 40.

   (2) Case 2 (where the diesel car maintenance cost is calculated according to specific units figured out from JNR's empirical data)

   Where the number of trains per day per line becomes in excess of 90 to 140.

(3) Case 3 (where a happy medium between the two extreme cases 1 and 2 above is struck)

Where the number of trains per day per line is in excess of 50 to 60.

5. The electrification should preferably be phased in the following way.

| Step | Section |
|---|---|
| 1st | Manila - Sucat |
| 2nd | Sta Mesa - Guadalupe |
| 3rd | Manila - Meycauayan |
| 4th | Meycauayan - Malolos |

6. Before electrification, the sections to be electrified should complete the following projects.

(1) Double-tracking

(2) Improvement of platform facilities

(3) Removal of those congested level crossings which lie between Tayuman and Sta Mesa

(4) Construction of car depots at FTI and Malolos

(5) Strengthning of track structure

(6) Installation of automatic signalling system and interlocking system

7. It should be replaced the existing rails between Manila and Sucat and between Sta. Mesa and Guadalupe with 50 kg/m ones and the existing rails in other sections which will electrified with 37 kg/m ones for the purpose of strengthning the track structure.

Rehabilitation of the spacing of sleeper and ballast thickness to the dimensions as required by the existing stndards.

Installation of anti-creeper for preventing rail creeping.

8. The choice between AC and DC systems has a great bearing upon the overall economy of the electrification. Thus, technical studies have been made about these two systems. It is found that the DC system is better than the AC system so far as the electrification costs including those for rolling stock are concerned. But the decision should await further close investigations.

9. The costs for the ground facilities necessary for the electrification of the Malolos-Sucat section are roughly estimated as follows.

- AC electrificition: approx. ₱ 126 x $10^6$
- DC electrification: approx. ₱ 139 x $10^6$

Given that the number of cars required is 300, the costs for them are roughly estimated as follows.

- AC electrification: approx. ₱ 830 x $10^6$
- DC electrification: approx. ₱ 760 x $10^6$

10. What is to be improved before electrification is as follows.

(1) Formulation of maintenance standards

(2) Improvement in ticket checking system

(3) Improvement in passenger service facilities

(4) Upgrading railway workers' state of art

# REPORT ON STUDY OF ELECTRIFICATION OF THE PNR COMMUTER SERVICE

## 1. Introduction

The study team had an impression that the transportation in Manila involved ramified problems and was very difficult to use. One cannot tell when he comes by a taxi and when he will reach the place he is going to go to. In a host of cities in the world, railway construction or improvement projects are planned and implemented for the punctuality and reliability the railway service has.

Although PNR has amassed more weight as an important means of transport in Metro Manila than it was several years ago, its facilities and organization leave much to be desired in view of punctuality and reliability. One of major problems standing in the way of PNR's efforts for facilities improvement is squatters. This problem is too heavy to solve if PNR alone must tackle. Anyway, PNR seems obliged to offer inexpensive, quick and punctual railway services as early as possible for the purpose of promoting the resettlement of the squatters.

The economy and reliability of the railway will be even more amplified if it is electrified.

The electrified railways increase the transport efficiency because they have high acceleration-deceleration characteristics, and bring about many benefits to both the general public and the country as a whole. To the country, the electrified railways do good by saving energy and foreign currency requirements. To the general public, the electrified railways also are beneficial because they offer rapid, reliable, inexpensive and time-saving transit services. But, the electrification calls for vast sums of initial investments, and will not pay for itself unless the daily number of trains is in excess of 60 to 100.

It should be added by the way that the electrification alone will not be enough in the reinforcement of transport capacity.
Even since the beginning of its commuter service, PNR has experienced a sharp increase in passenger traffic every time it increased train

services. This is very encouraging to the electrification project. If PNR can offer reliable and inexpensive transit services, it will be conveying 550,000 passengers in 1987 as forecast by the Pacific Consultants International (PCI).

What is most important for PNR will be to promote the projects for enhancing the transport capacity with the electrification in mind. The projects for enhancing the transport capacity refer to those which will make it possible for PNR to manage 550,000 passengers by 1987, and are not limited to the matter of choice between dieselization and electrification.

These are in essence just the same as what was proposed by PCI.

The report submitted herewith is designed to deal with PNR's commuter service electrification project, and only covers the high spots of the electrification vs. dieselization comparison studies and the portion of the project related to electrification that must be completed before electrification.

## 2. Effects and Necessity of Electrification

### 2-1 Introduction

The world's first electric railway was put to operation in Berlin in 1879. Ever since, the electric railway has made marked progress, interlacing cities and their peripherals with rapid transit networks. The electric railway has made a great point in its application to tunnels.

The electrification of the railways has been pushed forward to meet various needs, including improvement in transportation, the saving of coal and oil, and modernization of business operations, playing a vital role in the railway transport.

The total operating kilometerage, electrified kilometerage and electrification ratio in major countries in 1977 are shown in Table 2-1. JNR is carrying by electric railways about 84% of railway passengers and cargoes, respectively.

Table 2-1 Electrification of railways in major countries in the world

| Country | Operating kilometerage | Electrified kilometerage | Electrification ratio, % |
|---|---|---|---|
| U.S.S.R. | 138,260 | 39,008 | 28.2 |
| W. Germany | 28,796 | 10,081 | 35.0 |
| Italy | 16,077 | 9,632 | 59.9 |
| France | 34,834 | 9,592 | 27.5 |
| Sweden | 12,104 | 7,491 | 61.9 |
| India | 60,508 | 4,448 | 7.4 |
| U.K. | 18,118 | 4,014 | 22.2 |
| U.S.A. | 539,032 | 2,328 | 0.4 |
| Japan | | | |
| JNR | 21,276 | 7,813 | 36.7 |
| Private railways | 5,591 | 4,918 | 88.0 |

## 2-2 Electrification and its advantages

At present, PNR uses diesel-electric and diesel locomotives for transport of passengers and freight and also uses diesel railcars for passenger transport. The commuter service is undertaken by diesel railcars.

Table 2-2 shows the merits of electrification (comparison of electric car traction system with diesel car traction system). Most of data used in Table 2-2 are based on JNR's achievements. The merits of the electrification may be summarized as follows.

1. Reduced transport costs

   (1) The energy cost is about 50%.

   (2) The rolling stock maintenance cost per car-km is about 40 to 50%.

   (3) The service life of rolling stock is longer.

   (4) The operating efficiency of rolling stock and the productivity of train crew are 10 to 30% higher.

2. Increased speed and transport capacity

   The electric car has a high tractive force and exhibits high acceleration and deceleration characteristics, making it possible to increase the running speed and transport capacity. Figs. 2-1 and 2-2 show the running curves of electric car (EC) and diesel railcar (DC) operating at a slope of 0% and 1.0% over an inter-station distance of 1.7 km and 1.2 km. Table 2-3 is a summary of the calculations of running time, speed, etc.

   The train make-ups, output horsepower and other factors used in the calculations are as follows.

EC

Type : JNR's typical commuter train, 103 series

Consist : 6 cars (4 motor cars + 2 trailer cars)

Output : 1,760 kW (110 kW per motor)

Boarding efficiency : 200%

DC

Type : Same as used on PNR's commuter lines

Consist : 6 cars

Output : 1,080 PS (180 PS per engine)

Boarding efficiency : 200%

The inter-station distance was set at 1.2 km and 1.7 km because the mean inter-station distance in the sections Manila-EDSA and Manila-Sucat is about 1.2 km and 1.7 km, respectively. There is an upgrade of some 1.0% over a considerably long span near Sucat, and a study was also made with respect to this gradient.

The calculation results for an inter-station distance of 1.7 km are as follows.

(1) 0% grade section

The running time is 110 sec. with EC and 156 sec. with DC, showing a difference of 46 sec. The maximum running speed is 80 km with EC and 55 km with DC, and the mean running speed is 55.6 km/hr. and 39.2 km, respectively, with the result that the mean running speed of DC is about 70% of that of EC.

(2) 1.0% grade section

The running time is 122 sec. with EC and 192 sec. with DC, making a large difference of 70 sec. between them.
The maximum running speed is 75 km/hr. and 44 km/hr., respectively, revealing that the reduction in speed from the data in (1) about is much more with DC than with EC. EC shows a mean running speed of 50.2 km/hr., and DC 13.9 km/hr. or 65% of EC.

Where the inter-station distance is short as in the case of commuter lines or where there are many slopes in the track, EC has every advantage over DC as it delivers higher speed, makes the running time and the headway shorter and increases the transport capacity.

3. Improved transport services

The travelling time can be reduced, and the riding comfort is improved because EC emits no exhaust and generates much less noise and vibration.

4. Others

In addition, the electrification has the following advantages.

(1) Energy-saving thanks to high energy efficiency.

(2) While DC can run on oil alone, EC operates on electricity available from hydraulic power, oil, coal, LNG, geothermal power, atomic power and other various forms of energy and is a standout, particularly against oil crisis which is always in store.

(3) Promotion of the development in the areas along the railways and dispersion of population from urban areas to suburban areas.

(4) The operating troubles are reduced by 20 to 30%

Given above are only the merits of electric car traction system. But, the electric car traction system has also drawbacks. Namely, electrification calls for vast sums of investments in ground facilities, and EC costs more than DC of the commuter service type. Thus, we must compare the economics of elecrfication and dieselization in wide perspective for sizing up the advantages of electrification.

Table 2-2 Effects of electrification (as viewed from the comparison between electric car traction and diesel car traction)

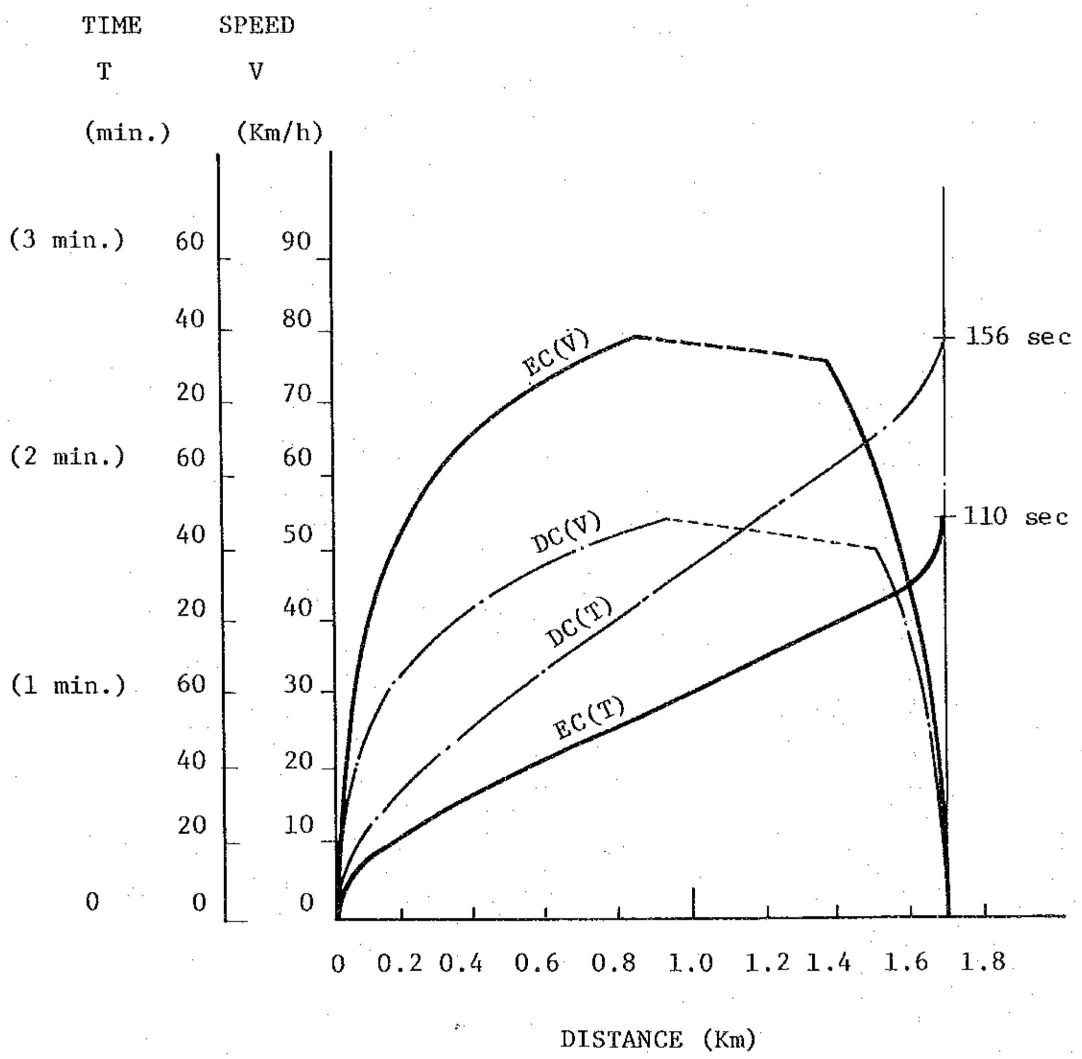
| Resultant effect | Contributing factors | Details |
|---|---|---|
| Reduced transport cost | 1. Reduced energy cost | Electric car traction is higher in energy efficiency than diesel car traction. The ratio of electric to diesel energy cost per 10-ton-car-kilometer is about 0.5 when calculated based on the prices of electricity and light oil in Philippines. |
| | 2. Reduced rolling stock maintenance cost | In the electric car traction system, there are few parts requiring servicing, except for pantograph sliders and some other specific consumables, and the overall maintenance cost is lower compared with the diesel car traction system. The diesel traction uses high-temperature reciprocating engines, and the maintenance costs are higher, accordingly. The ratio of electric to diesel maintenance cost per car-kilometer is about 0.4 to 0.5. |
| | 3. Longer service life of rolling stock | Electric car is longer in service life than diesel car. |
| | 4. Increased rolling stock operating efficiency | The electric car is higher in speed, requires no fuel oil supply, and is about 1.2 times as much in daily car-kilometers as the diesel car. This means that a smaller number of electric cars will do on an equal carloading basis. |
| | 5. Increase productivity of train crew | The electric car is higher in acceleration and deceleration and also higher in speed than diesel car, and can make the train-hour 10 to 30% shorter than diesel car. Namely, a smaller number of crew members will do on an equal carloading basis. |

| Resultant effect | Contributing factors | Details |
|---|---|---|
| Increased transport capacity | | The electric car delivers a higher tractive force, and is higher in speed, acceleration and deceleration because it can use an electric brake. All these combine to increase the number of train services, sending up the transport capacity 10 to 40% more than diesel car though it is dependent on track conditions. |
| Improved services | 1. Reduced travelling time | The transit time can be reduced by 10 to 30%. This is particularly noticeable where the track has slopes. |
| | 2. Improved riding comfort | The electric car emits no exhaust, and is less in noise and vibration level, improving the riding comfort greatly. |
| Others | 1. Reduced energy consumption | The electric car operation reduces PNR's power costs, and also cuts down on the energy consumption in the Philippines. |
| | 2. Diversified energy sources | The diesel car runs on oil energy alone, but the electric operation can use whatever energy sources we can convert into electricity, including petroleum, coal, LNG, geothermal energy, and nuclear energy. Namely, oil depletion is of no consequence to the operation of electric car so far as alternative energy sources are available. |
| | 3. Development of areas coming under the influence of railways | Improved railway services by electrification will send up the railway users, and at the same time increase the population along the railways, giving a spur to the development of the areas along the railways. Also, the city population can be decentralized. |
| | 4. Development of industry | The electrification project requires volumes of materials and supplies, and stimulate the related industries. |
| | 5. Reduced train troubles | The electric car is higher in reliability than diesel car, because it has fewer movable parts in the drive and transmission than the diesel car. The ratio in frequency of troubles of electric car to diesel car per car-kilometer is 0.7 to 0.8. |

FIG. 2-1 EC VS. DC PERFORMANCE COMPARISON

(Where the interstation distance is 1.7 KM on the average)

0% grade section




1% grade section

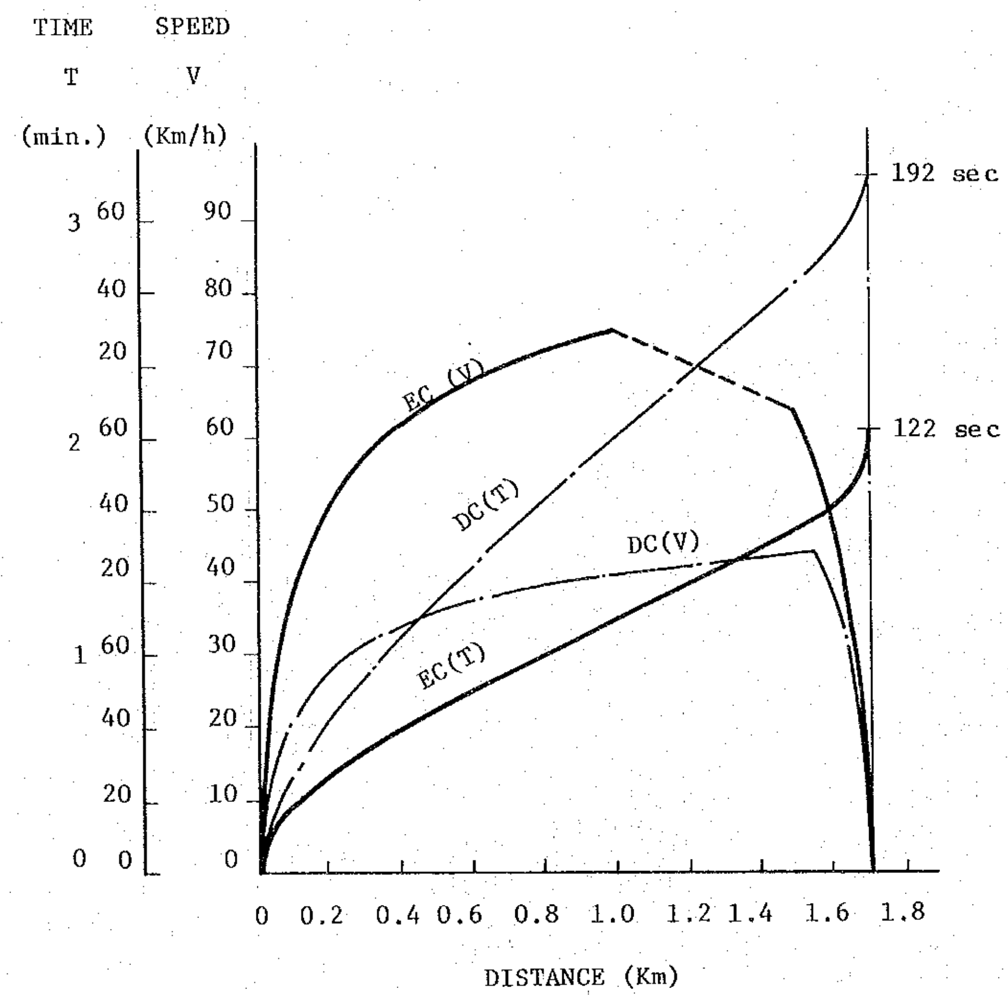
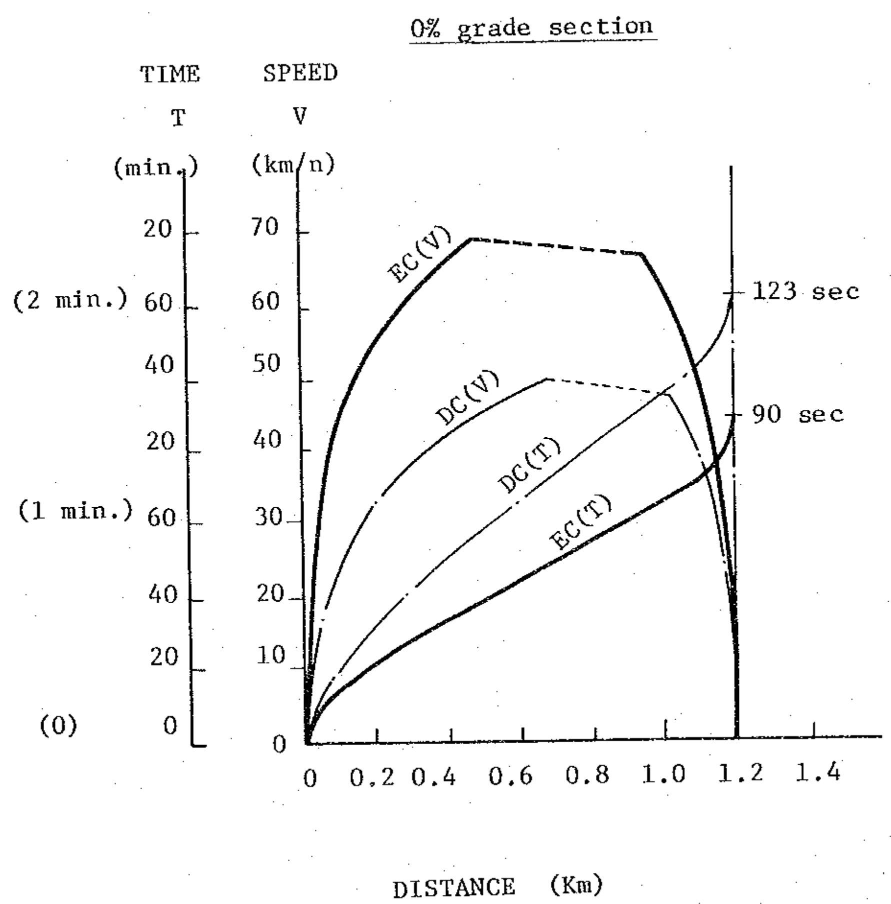


FIG. 2-2 EC VS. DC PERFORMANCE COMPARISON

(Where the intersection distance is 1.2 KM on the average)



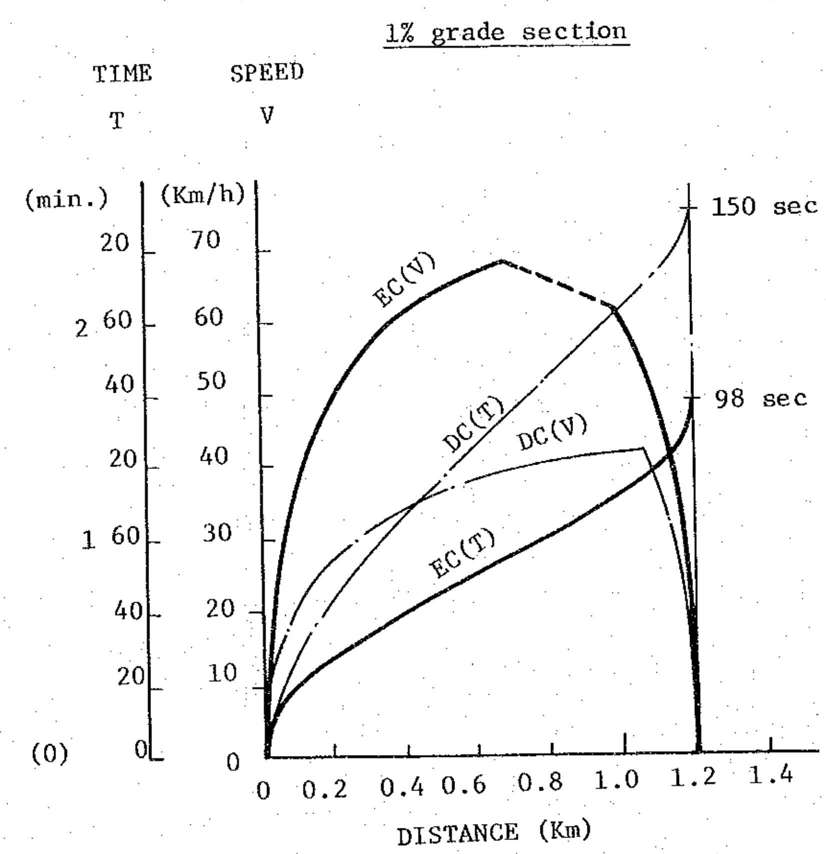



Table 2-3 Electric car vs. diesel car performance comparison

| Interstation mean distance | | 1.2 Km | | 1.7 Km | |
|---|---|---|---|---|---|
| Particulars | Track grade | Electric | Diesel | Electric | Diesel |
| Make-up | - | 6 cars | 6 cars | 6 cars | 6 cars |
| Make-up weight, tons | - | 292 | 267 | 292 | 267 |
| Running time | 0 o/oo | 1'30" | 2'03" | 1'50" | 2'36" |
| | 10 o/oo | 1'38" | 2'30" | 2'02" | 3'12" |
| Acceleration, km/hr./sec. | 0 o/oo | 2.3 | 1.1 | 2.3 | 1.1 |
| | 10 o/oo | 1.7 | 0.6 | 1.7 | 0.6 |
| Deceleration, km/hr./sec. | 0 o/oo | 2.5 | 2.0 | 2.5 | 2.0 |
| | 10 o/oo | 2.5 | 2.0 | 2.5 | 2.0 |
| Inter-station max. running speed, km/hr. | 0 o/oo | 70 | 50 | 80 | 55 |
| | 10 o/oo | 70 | 42 | 75 | 44 |
| Inter-station mean running speed, km/hr. | 0 o/oo | 48.0 | 35.1 | 55.6 | 39.2 |
| | 10 o/oo | 44.1 | 28.8 | 50.2 | 31.9 |

## 2-3 Comparison of electrification and dieselization from the economic viewpoint, and the time of electrification

The economic comparison study of electrification and dieselization can be made in various ways.

Employed here is a method using a "rate of additional investment profit" formula for calculating the ratio of the difference in profits to the difference in investments between electrification and dieselization. This method helps define the time of electrification if the electrification is taken above the dieselization.

The rate of additional investment profit is compared with the prime rate; if it is higher, it means that the electrification is given the palm.

It is difficult to foretell the future profits with accuracy, and the difference in annual expenditures is taken up instead of the difference in profits.

Rate of additional investment profit = (Annual expenditures due to dieselization - Annual expenditures due to electrification) ÷ (Investments in electrification - Investments in dieselization) × 100%

Here, the investments refer to the total of the costs for rolling stock and ground façilities, and the annual expenditures to the total of deprecision costs, maintenance costs and power costs.

It should be noted that the investments which become necessary with increase in the number of trains irrespective of whether electrification or dieselization, e.g., costs for the improvement and extension of platforms, employment of automatic signalling system and modernization of station facilities, are omitted.

Table 2-4 shows data on which the calculations were made. Table 2-5 and Fig. 2-3 shows the results of economic comparison study with respect to double-tracking. The rate of additional investment profit is given by the following formula.

Case 1. (Where DC maintenance cost is calculated according to PNR's empirical data)

$$R = \frac{1.57\ N.T - 118.8}{2,127 + 2.89\ No.T - 0.09\ N.T} \times 100\%$$

Case 2. (Where DC maintenance cost is calculated according to specific units figured out from JNR's empirical data)

$$R = \frac{0.38\ N.T - 118.8}{2,127 + 2.89\ No.T - 0.09\ N.T} \times 100\%$$

Where, R: rate of additional investment profit

N: required number of trains per day

No: number of trains per day to be operated by DCs existing before electrification

T: number of cars per train

The formulas given above are different from those appearing in the interim report. This is because while JNR's data alone was used for computations in the interim report, the computations here are based on PNR's data and on the condition that DCs which are to be dispensed with because of electrification are traded off to other non-electrified sections at half their brandnew price.

In case 1, R is 6% to 7% if N = 30 and No = 10 to 30, or is more than 10% if N = 40. This justifies electrification right now of the South Line whose N value is 36 at present.

In case 2, that is, when DC maintenance can be accomplished at an ideal cost, R is 3.4 to 3.9% if N = 90 and No = 10 to 30. The electrification will be accomplished economically when the prime rate is as low as 3.4 to 3.9%. If the prime rate is high, the timing of electrification should preferably be around 120 to 140 in terms of N value.

The two cases above are polar apart with respect to the estimation of DC maintenance cost, and the happy medium should be struck. Namely, with N at 60, R is estimated to be 9% to 10% (No = 10 to 30).

Table 2-4 Data for economic calculation

| Item | Unit | Value | Remarks |
|---|---|---|---|
| Costs for rolling stock | $10^3$ ₱/car | | |
| • Electric car | | 2,524 | |
| • Diesel car | | 2,121 | |
| Costs for ground facilities | $10^3$ ₱/km | 2,127 | |
| Economic life (years of depreciation) | yr. | | |
| • Electric car | | 23 | |
| • Diesel car | | 20 | Upon arrangements with PNR |
| • Ground facilities | | 20 | |
| Rolling stock repair costs | ₱/car-kilometer | | |
| • Electric car | | 0.54 | |
| • Diesel car | | 4.28 | Case 1: Based on PNR's empirical data |
| | | 1.06 | Case 2: Based on values estimated from JNR's empirical data |
| Energy costs | | | |
| • Light oil | ₱/lit. | 1.21 | |
| • Electricity | ₱/kWh | 0.24 | |
| PNR labor costs | ₱/yr. | 7,300 | Upon arrangements with PNR |

Table 2-5 Results of economic comparison

(in $10^3$ ₱)

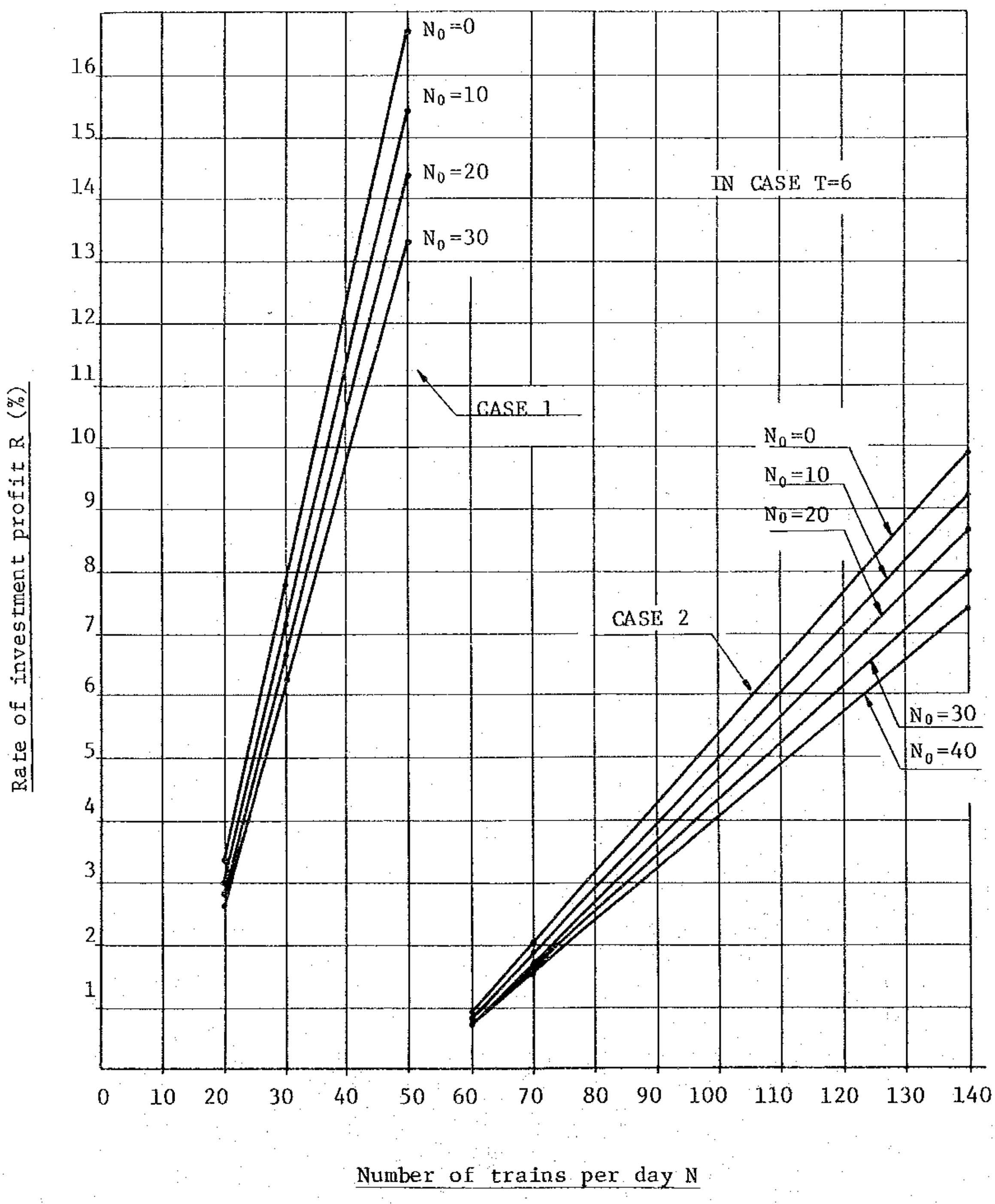
| Item | Electrification | Dieselization | Difference |
|---|---|---|---|
| Amount of investments | 2127. + 6.34N·T − 3.54No·T | 6.43 (N − No)·T | 2127. + 2.89No·T − 0.09N·T |
| Rolling stock | 6.34N·T − 3.54No·T | 6.43 (N − No)·T | 2.89No·T − 0.09N·T |
| Ground facilities | 2127. | | 2127. |
| Expenditures | 118.8 + 0.63N.T | 2.20N.T | 118.8 − 1.57N·T |
| Depreciation | | | |
| Rolling stock | 0.25 N.T | 0.29 N.T | -0.04 N.T |
| Ground facilities | 48.5 | | 48.5 |
| Maintenance | | | |
| Rolling stock | 0.20 N·T | 1.56 N·T | -1.36 N·T |
| Ground facilities | 70.3 | | 70.3 |
| Energy | 0.18 N·T | 0.35 N·T | -0.17 N·T |
| Rate of additional investment profit | $\frac{1.57N \cdot T - 118.8}{2127 + 2.89No \cdot T - 0.09N \cdot T} \times 100(\%)$ | | |

Note: In Case 2:

(1) The rolling stock maintenance cost (diesel) is given by 0.38NT.

(2) Rate of additional investment profit is given by (0.38NT − 118.8) x 100(%) ÷ (2,127 + 2.89NoT − 0.09NT)

FIG. 2-3 RATE OF INVESTMENT PROFIT VS. NUMBER OF TRAINS



## 3. Plan for the Electrification of PNR Commuter Service

### 3-1 Estimate of Traffic Volume

The PNR commuter traffic demand forecast is made in detail in the report, "IMPROVEMENT OF PNR COMMUTER SERVICE", submitted in Mar. 1976 by Pacific Consultants International (P.C.I.).
Thus, the traffic demand (sectional maximum traffic demand by direction in peak hours) for the years 1987 and 2000 in Table 3-1 which was calculated by P.C.I. is taken as a major premise of the plan.

Table 3-1 Sectional maximum traffic demand by direction in peak hour

| Section | Direction | Traffic demand (passengers/hour) | |
|---|---|---|---|
| | | 1987 | 2000 |
| Gelmart - Carmona | up | 1,291 | 2,156 |
| | down | 1,030 | 1,719 |
| Pio del Pilar - Gelmart | up | 5,050 | 8,433 |
| | down | 4,157 | 6,942 |
| Paco - Pio del Pilar | up | 7,538 | 12,347 |
| | down | 5,981 | 10,199 |
| Sta Mesa - Paco | up | 10,532 | 17,589 |
| | down | 9,658 | 16,130 |
| Manila - Sta Mesa | up | 18,200 | 30,287 |
| | down | 16,892 | 28,220 |
| Sta Mesa - Guadalupe | up | 11,591 | 18,285 |
| | down | 10,931 | 19,034 |
| Manila - Caloocan | up | 15,324 | 25,591 |
| | down | 15,652 | 26,139 |
| Caloocan - Meycauayan | up | 11,839 | 19,764 |
| | down | 10,559 | 17,514 |
| Meycauayan - North | up | 4,829 | 8,064 |
| | down | 4,905 | 8,191 |

## 3-2 Plan of Train Operation

According to the traffic demand in Table 3-1, the headway in the peak hours is calculated with respect to 4 cars, 6 cars and 8 cars of which a train is to be made up. The results are as shown in Table 3-2. For the calculation, it was assumed that the boarding efficiency is 200% (280 passengers per car) and that the South and the North Line are operated independent of each other in the Manila-Tayuman "Y" section.

As is clear from Table 3-2, the Manila-Sta Mesa section, which has the heaviest traffic, is expected to have a headway of 3.7 min. if the train is made up of 4 cars and 5.5 min. if the train is made up of 6 cars. Either way, the section is the most busiest.

On the South Line, the headway becomes longer the farther we go to the south of Manila. The Sucat-Carmona section will be fully accommodated if a train service is available every hour or so because the demand there is very little. The East Line will require a headway of 5.8 min. for 4-car consist or 8.7 min. for 6-car consist.

The North Line has much passenger traffic because it is concerned with a new regional development project.
The Meycauayan-Malolos section will necessitate a headway of 13.6 min. with a 4-car makeup and 20 min. with a 6-car makeup.

From the above, the following master plan has been established for the train operation in 1987.

Table 3-2 Required headway in each section

[unit: minute]

| Section \ No. of cars per train \ Year | 1987 | | | 2000 | | |
|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 4 | 6 | 8 |
| Sucat - Carmona | 52 | | | 31 | | |
| Pio del Pilar - Sucat | 13.2 | 19.8 | 26.4 | 8.0 | 12.0 | 16.0 |
| Paco - Pio del Pilar | 8.9 | 13.3 | 17.8 | 5.4 | 8.1 | 10.8 |
| Sta Mesa - Paco | 6.4 | 9.6 | 12.8 | 3.8 | 5.7 | 7.6 |
| Manila - Sta Mesa | 3.7 | 5.5 | 7.4 | 2.2 | 3.3 | 4.4 |
| Sta Mesa - Guadalupe | 5.8 | 8.7 | 11.6 | 3.5 | 5.3 | 7.0 |
| Manila - Caloocan | 4.3 | 6.4 | 8.6 | 2.6 | 3.9 | 5.2 |
| Caloocan - Meycauayan | 5.7 | 8.4 | 11.4 | 3.4 | 5.1 | 6.8 |
| Meycauayan - Malolos | 13.6 | 20.4 | 27.2 | 8.1 | 12.1 | 16.2 |

3-2-1 South Line

(1) The number of passengers bound south of Sucat is reduced short. Thus, the trains should be turned back from Sucat as a terminal.

(2) The number of passengers bound south of Paco and Pio del Pilar snaps down. But the distance between Sucat and these stations is not too large to justify the shuttling service that will complicate the train operation schedule.

3-2-2 East Line

The Manila-Guadarupe section should be covered with through train services in order to relieve the passengers of changing trains at Sta Mesa. The reasons are as follows.

(1) The East Line has no less passengers than the South Line.

(2) The transit time from Manila to Guadalupe is about 20 min.; change at Sta Mesa will take the passengers much time., and this inconvenience should be avoided.

(3) Unless the Manila-Guadalupe section is not served with through trains, the trains for carrying the East Line passengers will have to be operated from Sucat. But this plan will lead to a decreased boarding efficiency between Sucat and Sta Mesa.

3-2-3 North Line

(1) The number of passengers going north beyond Meycauayan Station decreases abruptly, and Meycauayan Station should be taken as a terminal.

(2) The number of passengers using the Meycauayan-Malolos section is not so little, and this section should be served with through trains.

For all the lines, the number of cars per train in 1987 should be set at 6. This is because if 4-car trains are employed, the headway will be reduced to as short as 3 min. or so.

Fig. 3-1 shows a basic peak-hour train operation diagram in 1987 based on a scheduled speed of 40 km/hr. Table 3-3 shows the number of trains in peak hours during the 1987-2000 period. The number of cars per train is set at 6 for the year 1987 and 8 for the year 2000, except for the Sucat-Carmona section.

FIG. 3-1

FUNDAMENTAL TRAIN DIAGRAM IN PEAK HOUR IN 1978

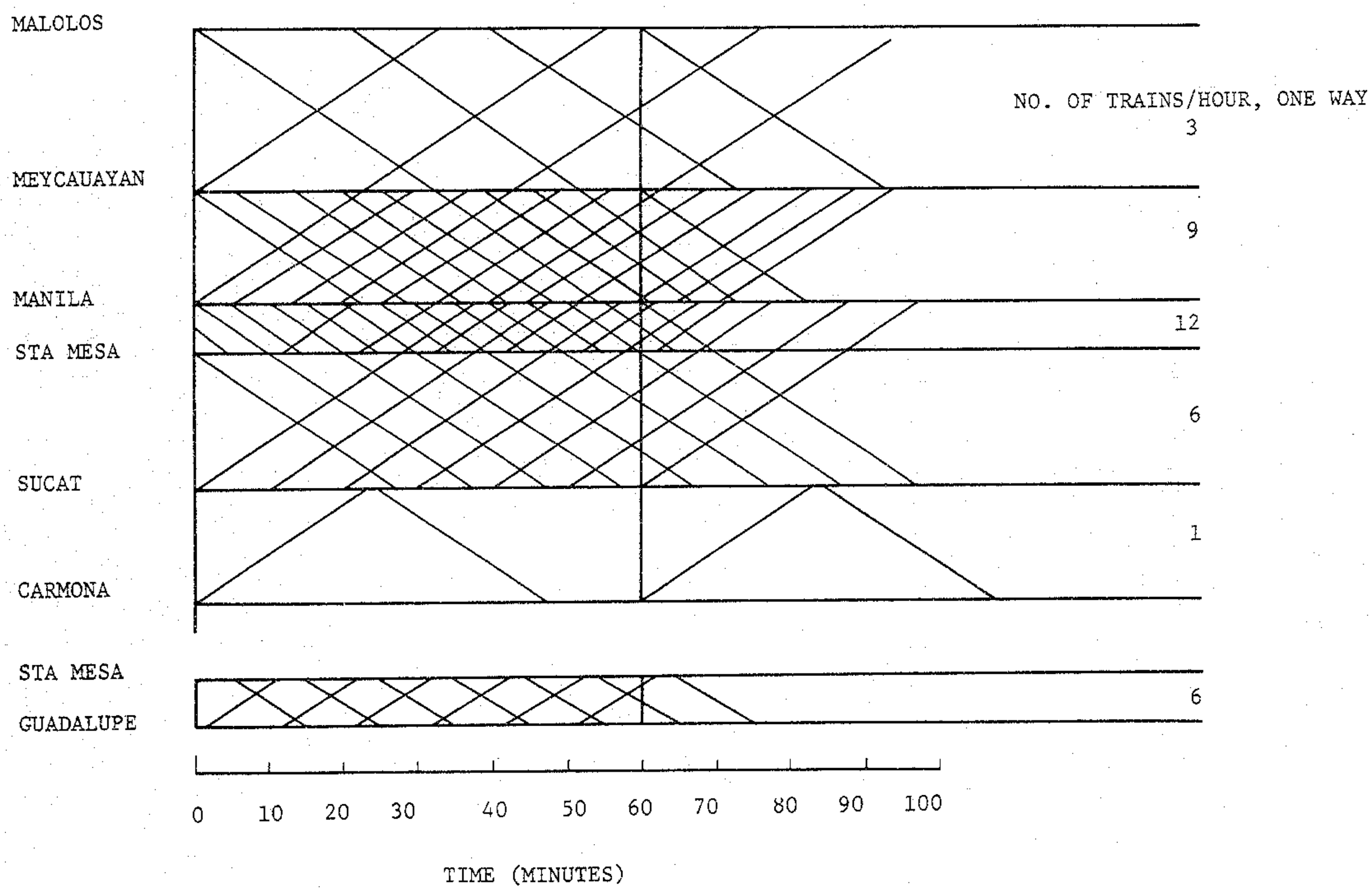


Table 3-3 No. of trains in peak hour per one way

| Line \ Year | 1987 | 2000 |
|---|---|---|
| Manila - Sucat | 6 | 8 |
| Manila - Guadalupe | 6 | 8 |
| Sucat - Carmona | 1 | 2 |
| Manila - Meycauayan | 9 | 12 |
| Meycauayan - Malolos | 3 | 4 |

No. of cars per train are:

| | | |
|---|---|---|
| Sucat-Carmona line | | 4 |
| Other lines | | |
| | 1987 | 6 |
| | 2000 | 8 |

## 3-3 Electrification Project and Its Work Schedule

In para. 2-3, the economy of electrification and dieselization has been put to comparison study to show the relationship between the rate of investment profit and the number of trains, and it has been disclosed that the time when the electrification will be the advantage of dieselization varies widely depending on the maintenance cost of diesel cars.

In discussing the matters including the sections to be electrified, the mean of the values in Cases 1 and 2 has been taken as the maintenance cost for diesel cars. In this case, the electrification will become advantageous with a daily number of trains of 60 or more even if the prime rate is estimated high.

Table 3-4 Approximate number of trains per day

| Section | Dialy number of trains | |
|---|---|---|
| | 1987 | 2000 |
| Manila - Sucat | 204 | 252 |
| Manila - Guadalupe | 216 | 270 |
| Manila - Meycauayan | 202 | 246 |
| Meycauayan - Malolos | 62 | 92 |
| Sucat - Carmona | ca. 30 | ca. 60 |

As shown in Table 3-4, the daily number of trains in 1987 is expected to exceed 60 with the exception of the Sucat Carmona section. Thus, the sections in favor of electrification are Manila-Sucat, Sta Mesa-Guadalupe and Manila-Malolos. It seems reasonable that the electrification work should be carried out in the following order.

First of all, the Manila-Sucat section should be electrified, because it runs through the center of Metro Manila and reaches the resettlement area in Carmona.

To come second is the Sta Mesa-Guadalupe section; in time with electrification, the Manila-Guadalupe section should be served with through trains as it is now. If the Sta Mesa-Guadalupe section is delayed in electrification, lots of diesel cars will run into the electrified Manila-Sta Mesa section untowardly. If electric cars and diesel cars are run on the same track, the schedule speed will have to be reduced keeping in with whichever is the poorer in operating characteristics; namely, the high-speed, high-acceleration and high-deceleration characteristics of electric cars are bound to be impaired seriously. In addition, the exhaust gas from the diesel cars will foul the insulators over the electrified tracks, causing troubles in the electric system and inviting much maintenance labor and cost.

Then, the Manila-Meycauayan section and the Meycauayan-Malolos section should be electrified in turn.

## 4. Track Facilities Necessary for Electrification

### 4-1 Double-tracking Work

The double-tracking brings about the following benefits.

(1) While the capacity of a single track is said to be 80 to 100 train services a day at best, that of a double track is about three times as much.

(2) On a single track section, single train alone, whether up or down, is permitted to run between two adjacent stations, and a train to run in the opposite direction is required to wait at a station until the section just ahead of it is cleared. On the other hand, both the up and down trains have respective tracks, and can run faster as such a waiting time is not present.

(3) The double track yields some leeway in the arrangements of train operation diagram, making it possible to run trains to meet the needs of passengers.

(4) On the double track, the number of trains that may be affected by a delay of a train is smaller than on the single track, and such a delay can be recouped quickly.

(5) It is easier to make time for running machines for track maintenance than on the single track.

The track capacity can be roughly estimated according to the following formula.

$$N = \frac{1440}{t_i + S} \times f$$

Where, N: number of trains per day

$t_i$: running time between two-way stations

S: train operating time (empirically, 1.5 min.)

f: utilization factor (empirically, 0.6)

Applying the above formula to the PNR's single-track sections now operating for commuter service, the following results are obtained.

On the North Line, N for the Balagtas-Malolos section is the smallest with 49. Namely, this section determines the track capacity of the North Line. On the East Line, the Sta Mesa-Guadelupe section has no siding, and its N is 40. (See Table 4.1)

Since Table 9 dictates that the number of trains required in 1987 is 202 for the Manila-Meycauayan section and 216 for the Sta. Mesa-Guadalupe section, these sections must be double-tracked. For the Meycauayan-Malolos section, the number of trains in 1987 is 62, and it is necessary to install sidings or double-track the section. In 2000, N is expected to become 92, and it is imperative to double-track the section by 2000.

Table 4.1.1 Estimate of the North Line track capacity

| Section | | North-bound | | South-bound | | Mean running time | Track capacity |
|---|---|---|---|---|---|---|---|
| | | Passenger | Commuter | Passenger | Commuter | | |
| | Number of trains | 5 | 8 | 5 | 8 | Min. | Number of trains |
| MA | CN | | | | | | |
| CN | (ACA) | | | | | | |
| (ACA) | (PO) | | | | | | |
| (PO) | MY | 12.0 | 12.0 | 11.4 | 12.7 | 12.1 | 63 |
| MY | (MR) | | | | | | |
| (MR) | (BO) | | | | | | |
| (BO) | TAS | 12.8 | 16.7 | 12.6 | 16.7 | 15.2 | 51 |
| TAS | (GG) | | | | | | |
| (GG) | (YS) | | | | | | |
| (YS) | (DK) | | | | | | |
| (DK) | ML | 12.6 | 18.1 | 12.2 | 17.5 | 15.7 | 49 |

Table 4.1.2 Estimate of the East Line track capacity

| Section | | RL | MIA | Mean running time | Track capacity |
|---|---|---|---|---|---|
| SA | (COR) | | | | |
| (COR) | (BYN) | | | | |
| (BYN) | (ONA) | | | | |
| (CNA) | (ABO) | | | | |
| (ABO) | (BON) | | | | |
| (BON) | (NIG) | | | | |
| (NIG) | (HU) | | | | |
| (HU) | UPE | 20 | 20 | 20 | 40 |

As already discussed, the electrification will pay for itself when the daily number of train services has become in excess of 60 to 140. This range is due to the fact that the interest rate on the loans can vary.

The above is almost equal to the number of trains justifying the double-tracking.

As regards the time of electrification and double-tracking, the double-tracking work should precede as detailed in the interim report. The reasons are as follows.

(1) If the electrification is made for the single-track lines before double-tracking, the construction cost will be doubled because the electrification work is required again when the double-tracking work is made.

(2) If the electrification is preceded, much time and cost will be required since train services cannot be stopped.

(3) It will be easier to displace the squatters at the time of double-tracking than at the time of electrification.

(4) The double-tracking has a larger effect on the increase of track capacity than the electrification.

The double-tracking purposes to increase the track capacity to satisfy traffic demand, and is required irrespective of whether electrification or electrification is selected. Thus, its cost should not be included in the economic evaluation of electrification.

## 4-2 Improvement of Station Facilities

For the purpose of increasing the number of trains to meet the traffic demand in future, the platforms and track layouts for the turnaround stations and junction stations should be improved.
The time (turnback time) between the arrival and departure of a train at the turnabout station on a shuttling section is at present 9 min. on the Carmona Line and 5 min. on the Guadalupe Line, suggesting that the trains may be operated with a turnback time of about 5 min. without trouble.

Table 3.8 shows the hourly maximum number of trains on each section in 1987 and 2000. From this table, the turnback time in 1987 is estimated to be 5 min. for the Manila-Sucat section and the Manila-Guadalupe section, 5 min. for the Manila-Meycauayan section, and 10 min. for the Meycauayan-Malolos section.

In 2000, however, the turnback time is expected to be reduced to 3'45" for the Manila-Sucat section, Manila-Guadalupe section and the Manila-Meycauayan section. Accordingly, it will be necessary to use a platform each for arrival and departure so that a train can depart as soon as another arrives.

For Sucat, Guadalupe, and Meycauayan, two platforms are required for commuter trains. At Manila Station, the Sucat track, Guadalupe track and the Malolos track should be given two platforms each; namely, a total six platforms are required.

Sta. Mesa Station is a junction to the Guadalupe Line, and will be required to have four platforms in 2000.

With increase in the number of train services, such passenger facilities as overpasses and underpasses will have to be installed. These are necessary for the passengers to walk to and from a platform safely without being endangered by trains coming and going at short intervals. For the benefit of passengers, the overpasses or underpasses should be so provided as to give access from each platform to the roads on either side of the tracks. España, San Lazaro, new stations near Tuazon, Guadalupe and others will be necessary to have broad overpasses or underpasses as they have much passenger traffic.

The width of the pass is 1 m per hourly traffic of about 3,600 passengers, and should be at least about 3 m.

The improvement of station facilities is required to meet traffic demand, and should not be included into the economic evaluation of electrification because it is necessary irrespective of electrification or dieselization.

## 4-3 Grade Separation in Metro Manila

PCI proposed to install an about 4-km overpass from Tayuman Street to Ramon Magsaysay Boulevard passing over a new station to be installed on Tuazon Avenue.

The grade separation moderates road traffic, and brings about the following benefits.

Benefits goint to railways

(1) Railway crossings are withdrawn, dispensing with the maintenance costs (incl. wages, allowances and other labor costs, depreciation costs and repair costs) otherwise necessary.

(2) The space under the overpass can be used as warehouses, parking lots, etc. which will earn about 1% of the current land price as rental.

(3) The crossing accidents will be reduced, reducing the damages. The reduction in damages save the costs, increase in labor costs due to delayed train operations, and car depreciation costs.

Benefits going to the road traffic

(1) The grade separation saves the vehicular running costs, labor costs and other various time-dependent costs which will otherwise be required when the vehicles and passengers have to wait at the railway crossings.

(2) The grade separation dispenses with that part of fuel cost which is additionally required by every vehicle that must stop at the crossing and then start.

One policy is to share the costs for grade separation on the basis of the rate of resulting benefit. According to this method, the costs for a continuous grade separation will be divided between the municipality and railway corporation as given in Table 4.2.

Table 4.2 A method of sharing the costs for a continuous grade separation

| | | Railway corp. | Municipality |
|---|---|---|---|
| Costs for the costruction of overpass | Existing railway facilities | Amount corresponding to the benefits for the railway to enjoy | The remainder |
| | Additional railway facilities | All the costs | — |
| Costs for relocating cargo facilities, etc. | Existing railway facilities | Amount necessary for acquiring alternative land lots | Amount necessary for relocating facilities |
| | Additional railway facilities | All the cost | — |

The grade separation is available in the following two systems.

(1) Independent grade separation (spot)

(2) Continuous grade separation (stretch)

The independent grade separation is classified into two methods; one in which the railway is given an overpass, and the other in which the railway is given an underpass. The former is seen on Dimasalang Avenue and Ramon Magsaysay Boulevard. The independent grade separation has the following advantages.

(1) The construction work can be accomplished spot by spot starting with the places where the traffic volume is extremely heavy. Thus, considerable effects can be raised quickly at small investments.

(2) The dead weight of the structures is light, and the restrictions on slope are moderate. Thus, the costs for structures are comparatively less, and there are few parts that may run counter to the railway operations. The construction work becomes easy as a whole.

(3) As for Manila, it will be sufficient if some specific squatters alone are displaced.

On the other hand, the independent grade separation has the following drawbacks.

(1) The roadside environments change, often bringing about evil effects on the city planning.

(2) Where the place is phreatic with a high ground water level, an underpass requires a large-capacity drainage pump facility.

(3) If there are many crossings located close to each other and requiring grade separation, the overall construction cost becomes higher as compared with the continuous grade separation.

On the other hand, the continuous grade separation is available in the following types.

(1) Elevated railway

(2) Subway

The continuous grade separation has the following advantages.

(1) Many crossings can be grade-separated at once.

(2) The roadside environments change to a little degree from the viewpoint of city planning, and if the roadside is lined with business or amusement quarters, the evil effects of continuous grade separation are less. Thus, the construction work can easily be planned and implemented.

On the other hand, the continuous grade separation has the following drawbacks.

(1) The construction work becomes complicated and costly because it must be pushed forward while keeping railway services.

(2) The sunshine, TV and radio waves and environments are affected.

(3) The subway type is not suitable for such a place as Manila where the ground water level rises high in the rainy season, because its cost will become prohibitive.

The grade separation in such a large capital city as Manila must be made in a wide perspective, that is, with the future city plans, amenity, beauty and other various factors reckoned with. Thus, the costs of grade separation work cannot be of paramount importance in the selection of its types and designs.

In many cases, the grade separation is carried out in consideration of the degree of human forbearance with traffic jam. Namely, the number of trains alone cannot be a factor for the execution of grade separation work, but the number of vehicles forming a waiting queue due to the closure of the corssing is usually taken as a determinant.

In traffic engineering, the product of daily vehicular traffic volume and the total of the closed times of a crossing is taken as a clue. If the product exceeds 5,000 vehicle-hr./day, the grade separation is generally justified. If it exceeds 22,000 vehicle-hr./day, the grade separation is a must-do.

In Metro Manila, the daily number of trains is expected to be 420 in 1987; namely, the crossing will be closed 7 hrs. a day if it is closed an average 1 min. per train because the closing time per train ranges from 30 sec. to 2 min. Thus, for those crossings where the vehicular traffic is in excess of 3,000 a day, the grade separation will be necessary.

In the nature of things, the grade separation is closely concerned with road traffic demand, and its costs should not be included in the evaluation of electrification.

The following two methods are available in materializing the PCI's proposal for the continuous grade separation:

(1) Overpass work off the center of the right of way after displacing the squatters on one side of the right of way.

(2) Overpass work on the center of right of way after displacing the squatters from both sides of the right of way.

The choice between these should be made after due consideration of the feasibility of the work and the methods of using the space below the overpass.

The closing time within 30 to 35% per 100 to 120 sec. as set forth by the consultants to DPH may be realized only where the crossing is far apart from the station yard, but the closing time might possibly be longer in Metro Manila where the crossing is near the station.

Where the trains frequently pass by each other on the crossings, there may be the case where DPH's proposal is satisfied depending on train operation diagram. However, the train operation diagram cannot be fixed, and train operation troubles can also happen.

The scheme to establish a train operation diagram to make trains cross each other on crossings should therefore be considered as something of a basis upon which to determine the priority order of the constructions of independent grade separations or to mitigate traffic congestion halfway if there are many crossings for which grade separation is not provided.

## 4-4 Car Depot Facilities

PNR has a diesel car depot at the Manila Station yard, is going to install another depot at FTI this fiscal year in keeping with the addition of diesel cars.

PNR has a car depot plan according to repairing and inspections systems of its own as specified in Table 4.3.

Table 4.3 FTI inspection and repairing plan

| Type of inspection and repair | Cycle | Number of days for inspection/repair | Number of tracks in a shed |
|---|---|---|---|
| A repair | 2 years | 21 | 1 (6 cars' worth) |
| B repair | 1 year | 14 | 1 |
| Partial inspection | 6 months | 3 | 1 |
| Periodic inspection | 1 month | 1 | 1 |
| Daily start inspection | Every day | 20 min. | 1 |

Even after electrification, the plan will be applicable with a little modification because it leaves a margin as compared with Japan's standards. It should be noted that the FTI car depot be constructed by taking into account the difference between electric and diesel car with respect to the working space required for inspection and repair and also to the ceiling height required by construction gauge.

The electric car and diesel car are compared with reference to the space requirements for inspection and maintenance work below.

Diesel Car

| | |
|---|---|
| Center-to-center distance between repair tracks | 6.0 m |
| Distance between the center line of repair track and side wall | |
| Engine unloading side | 5.0 m |
| Opposite side | 3.5 m |

| | |
|---|---|
| Center-to-center distance between repair track and other track | |
| Engine unloading side | 6.5 m |
| Opposite side | 5.0 m |
| Distance between the center line of the regular inspection track and side wall | 3.5 m |
| Center-to-center distance between regular inspection tracks or between regular inspection track and other track | 5.0 m |
| Center-to-center distance between daily start inspection tracks or between daily start inspection track and other track | 5.0 m |
| Distance between the center line of daily start inspection track and side wall | 3.0 m |

Electric car

| | |
|---|---|
| Center-to-center distance between repair tracks | 7.5 m |
| Distance between the center line of repair track and side wall | 4.5 m |
| Center-to-center distance between regular inspection tracks or between regular inspection track and other track | 5.0 m |
| Distance between the center line of regular inspection track and side wall | 3.5 m |

The elevational arrangement of overhead crane facilities in the car shed shown in Fig. 4.1 is generally accepted as standard, and should be taken into the planning of the car shed.

The number of receiving tracks and storage tracks varies depending on the train operation diagram. Judging from the peak-hour passenger traffic demand (Table 3.1) determined by PCI and also from the passenger traffic statistics released in Jan., 1978, the hourly passenger traffic demand in 1987 and 2000 will be as shown in Fig. 4.2. From Fig. 4.2, a train operation diagram, is determined by way of reference (see the reference drawings), and the receiving and storage tracks are planned as shown in Table 4.4.

Figure 4.2-1 Estimated Hourly Traffic Volume of Southern Main Line

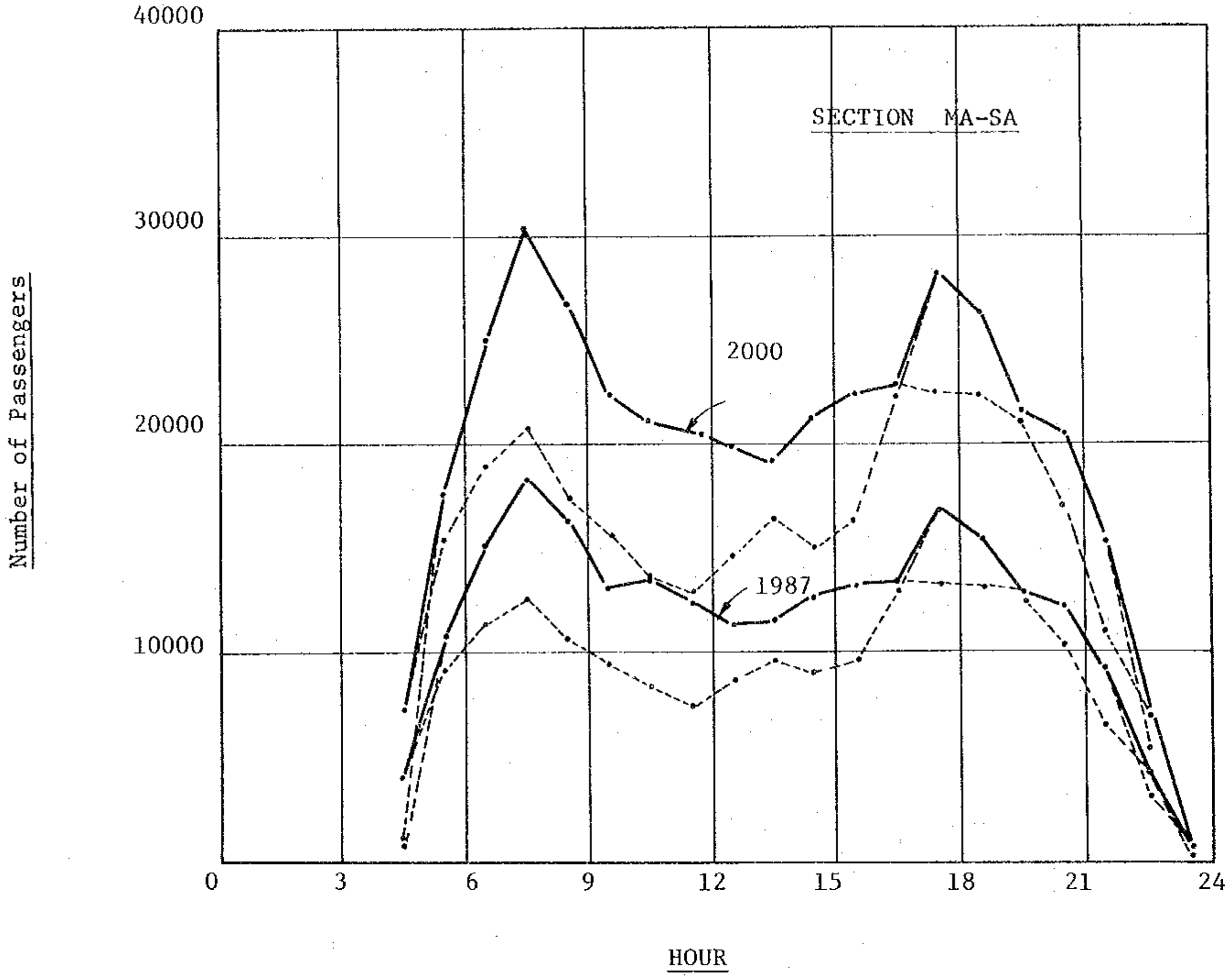


Figure 4.2-2 Estimated Hourly Traffic Volume of Southern Main Line

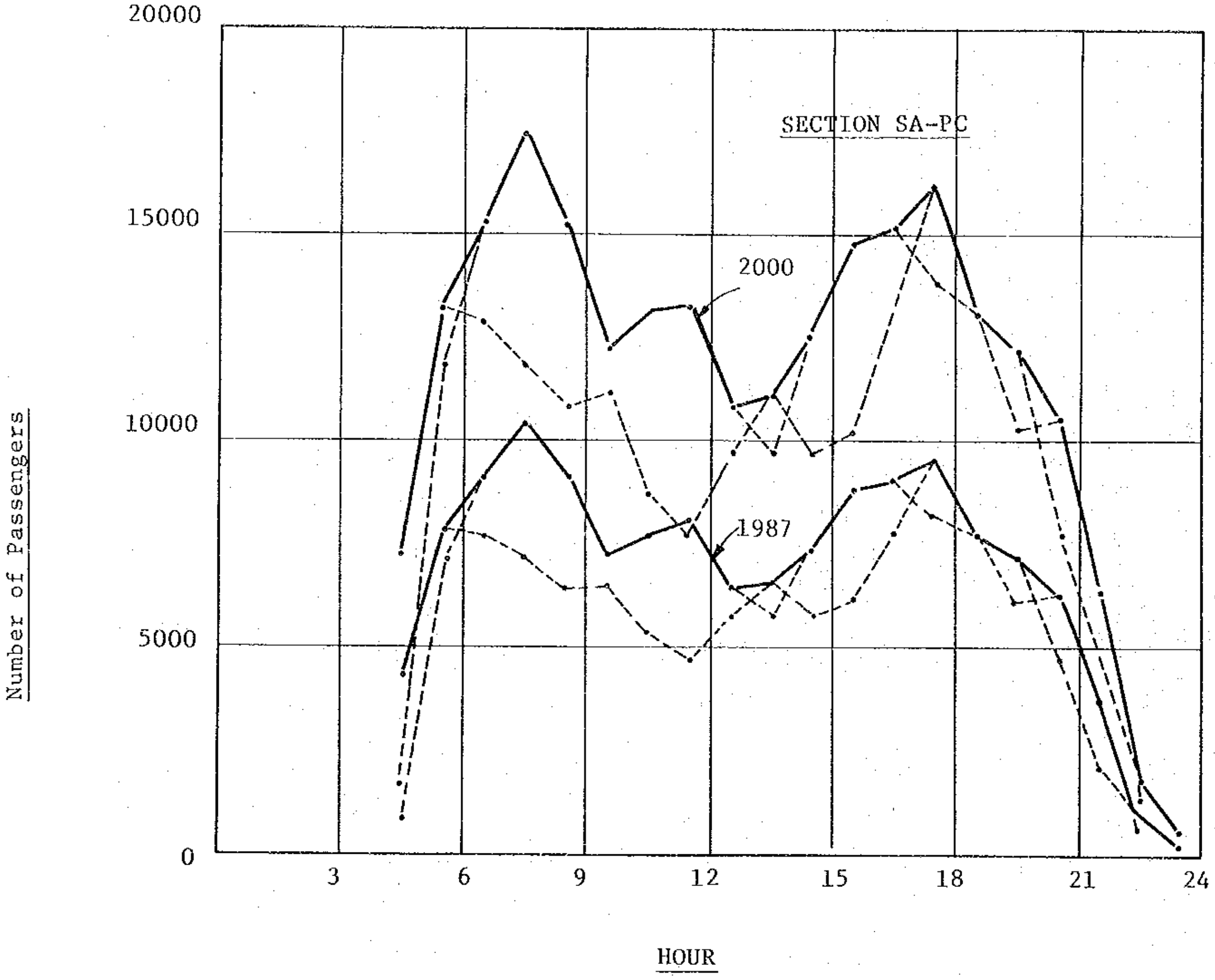


Figure 4.2-3 Estimated Hourly Traffic Volume on Northern Main line

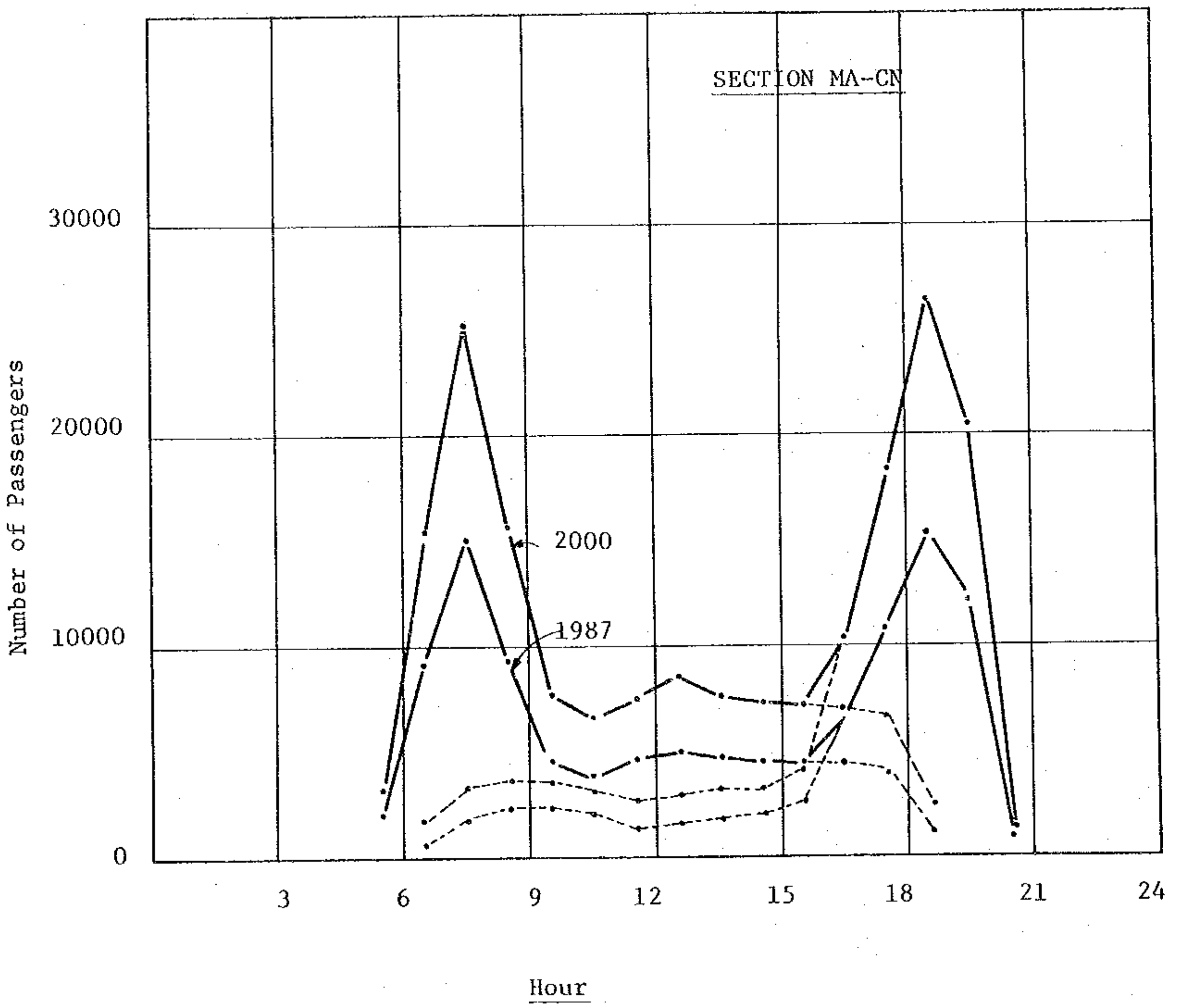


Figure 4.2-4 Estimated Hourly Traffic Volume of Northern Main Line

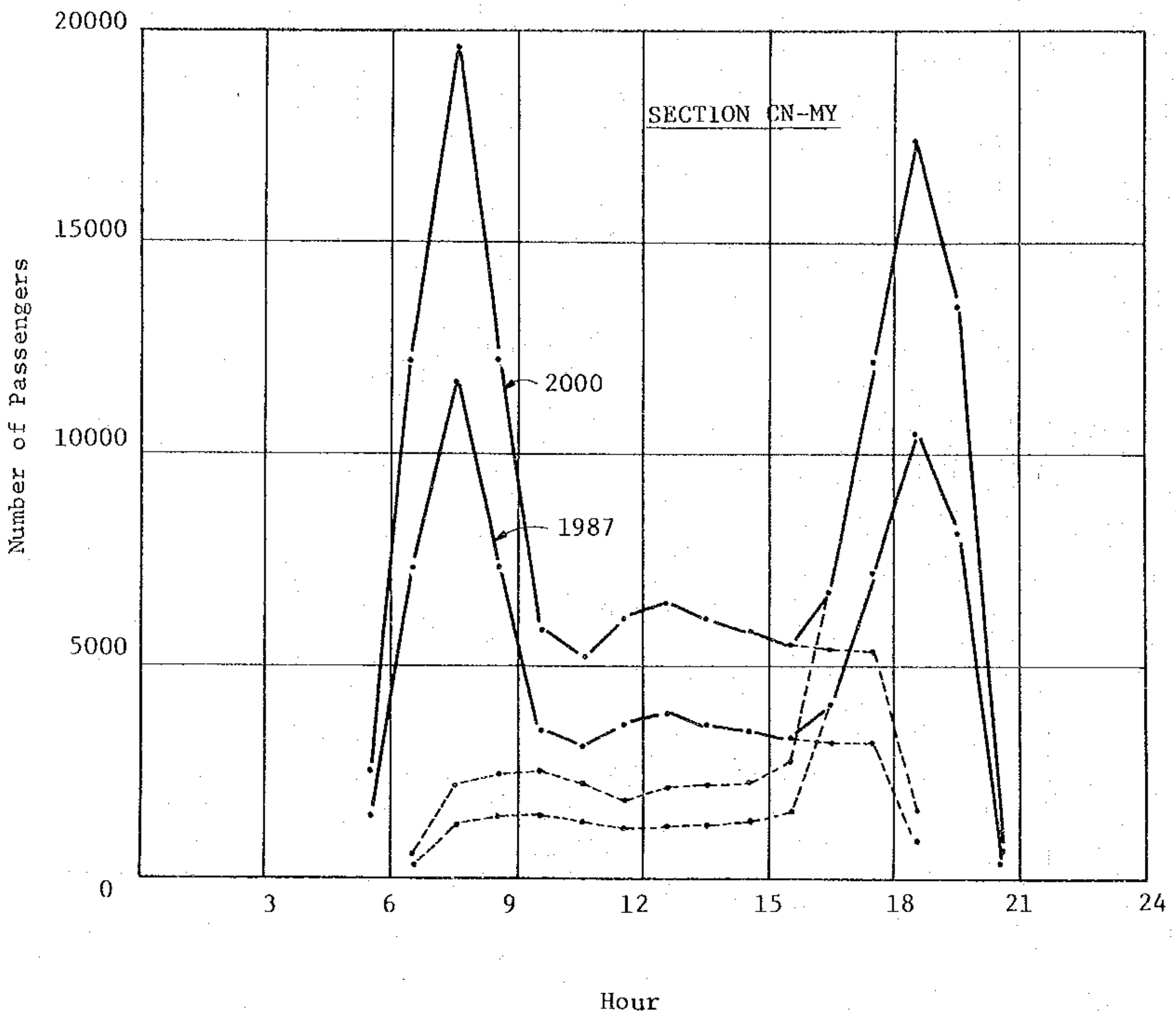


Figure 4.2-5 Estimated Hourly Traffic Volume of Northern Main Line

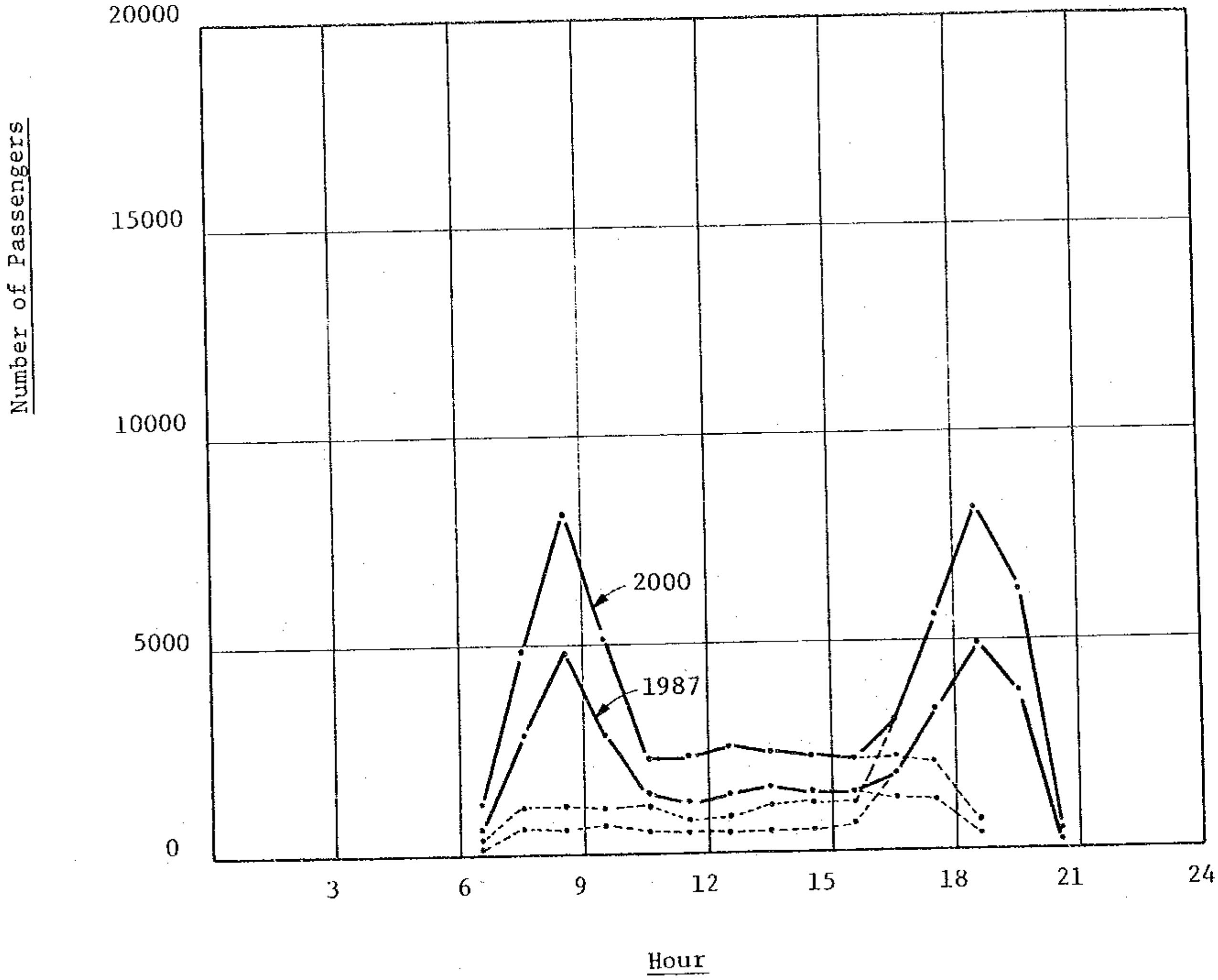


Figure 4.2-6 Estimated Hourly Traffic Volume on Guadelupe Line

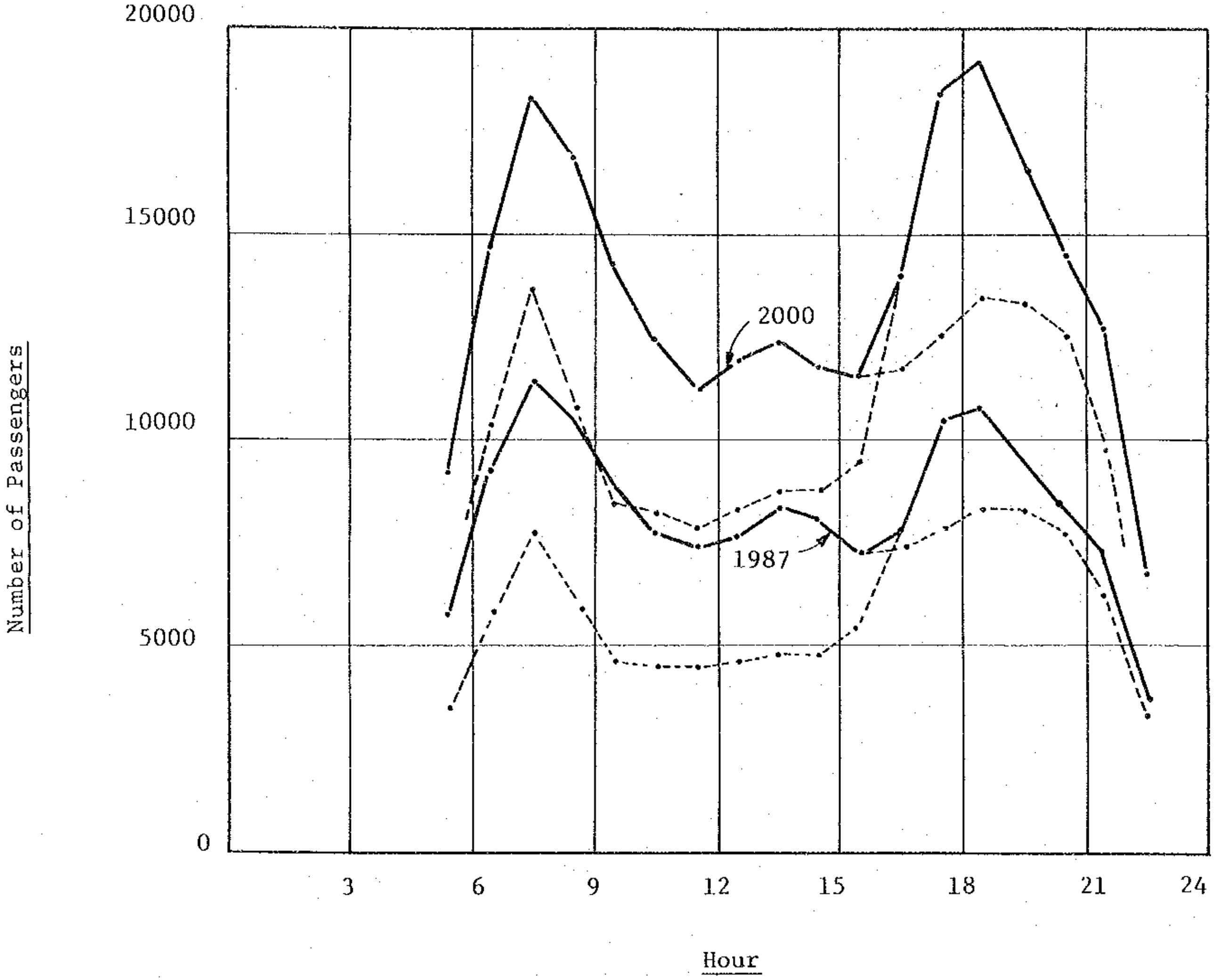


Table 4.4.1 Number of trainsets required

| Line | 1987 | 2000 |
|---|---|---|
| Sourth and East | 14 | 14 |
| North | 12 | 21 |
| Total | 26 | 35 |

Table 4.4.2 Recommended number of receiving tracks (excl. spare trainsets)

| Station | 1987 | 2000 |
|---|---|---|
| Malolos | 7 | 9 |
| Meycauayan | 2 | 2 |
| Caloocan | 1 | 1 |
| Manila | 5 | 6 |
| Gaudalupe | 2 | 2 |
| FTI | 8 | 14 |
| Sucat | 1 | 1 |

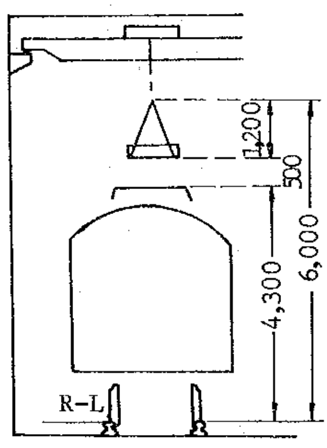



Fig. 4.1 Standard elevational arrangement of overhead crane

The car depot facilities explained above are also applicable to dieselization with the breadthwise clearances and ceiling height in the car sheds.

The resulting difference in investments between electrification and dieselization should therefore be counted in the evaluation of electrification. But it is discarded because it is negligibly small as compared with the total amount of investments.

## 4-5 Track Design and Materials

As frequently discussed, more train services are required in 1987 and 2000 than at present. The tracks carrying high-speed high-frequency trains naturally call for frequent maintenance work owing to the following reasons.

(1) The increase in the repetition frequency of dynamic loads accelerate the sinking of ballast, eventually developing track irregularity due to uneven settling.

(2) The higher the train speed is, the more the impact is given on the ballast, aggravating the ballast deformation.

(3) The high-speed running wheel loads acclerate the wear of rails and the rail cutting, aggravating the loss and wear of track materials.

In order to relieve the track of these evil symptoms, track maintenance work must be conducted frequently. For the purpose of avoiding inefficiency and diseconomy resulting from frequent maintenance work, however, the track structure should be strengthened in the following ways:

(1) To use rails of a larger area of section in order to reduce the pressure to be imposed on the ballast and at the same time to increase the rail service life and hence the replacement cycle.

(2) To increase the number of cross ties to reduce the pressure on the subgrade, and also to use tie plates to prevent cross railcutting on the sleeper.

(3) To use a thicker crushed stone ballast for the purpose of checking the growth of deformation of track due to vibrational acceleration.

(4) To increase the weight of track per unit length in order to reduce vibrational acceleration, that is, the irregularities of track.

(5) To fasten up the rails elastically for the purpose of reducing the vibrational acceleration of ballast in order to reduce the irregularities of track.

A quantitative comparison between the present and future of PNR's maintenance volume is made using an empirical formula below.

In Japan, the mean track maintenance volume required before adoption of periodic maintenance (1950's) and repair is given by the following empirical formula:

$$Y = 0.730 + 0.125PLM + 0.026W$$

Where, Y: number of service workers per km

P: maintenance volume coefficient relating to the difference in maintenance level

L: load coefficient

M: structure coefficient

W: annual passing tonnage

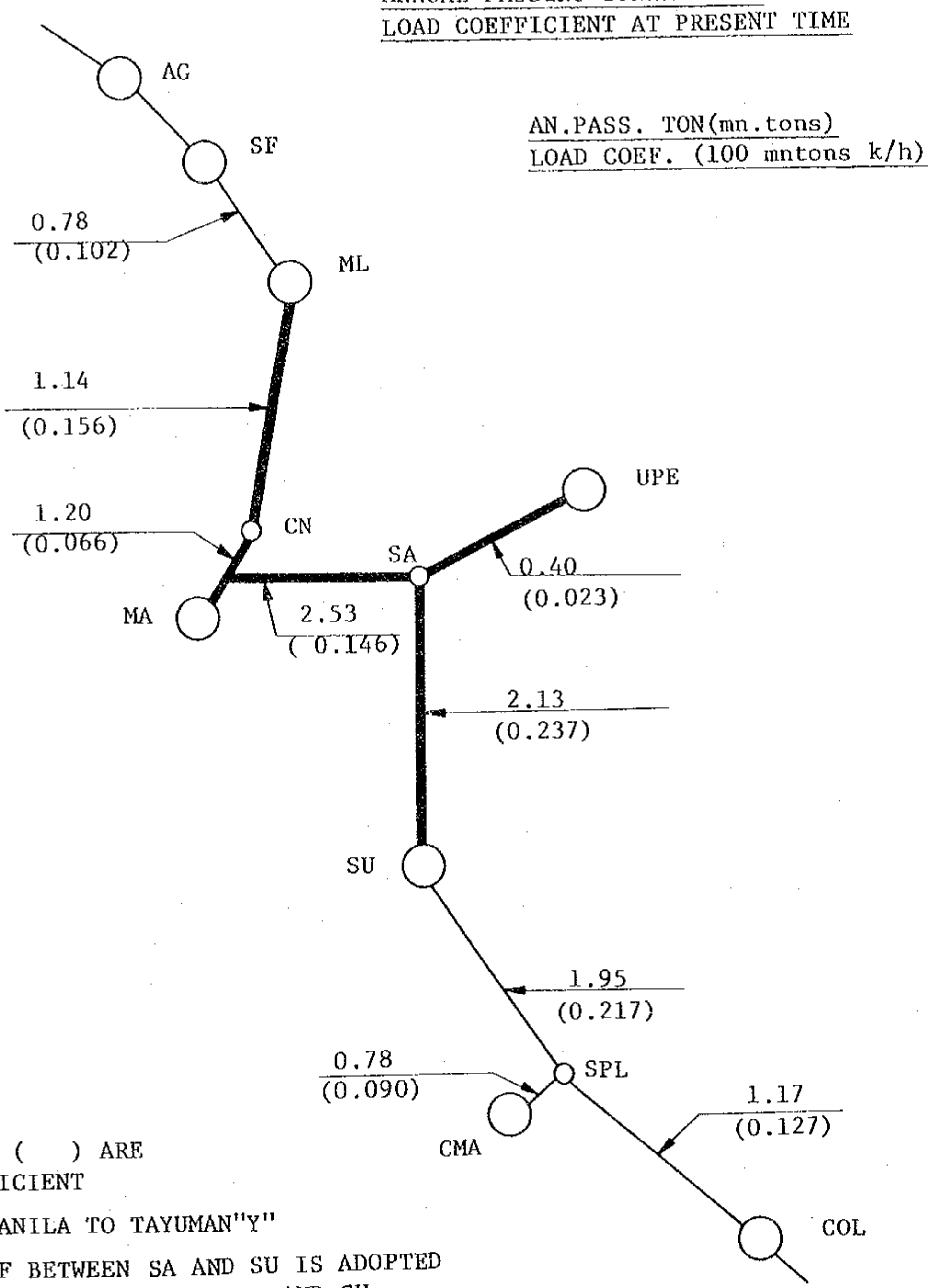
The load coefficient, L, is given by the following formula.

$$L = \Sigma\,((\text{rolling stock coefficients}) \times (\text{passing tonnage}) \times (\text{speeds}))$$

From the specification of PNR's rolling stock and the present and tentative future train operation diagrams, L is estimated as shown in Fig. 4.3.

Figure 4.3.1

ANNUAL PASSING TONNAGE AND LOAD COEFFICIENT AT PRESENT TIME



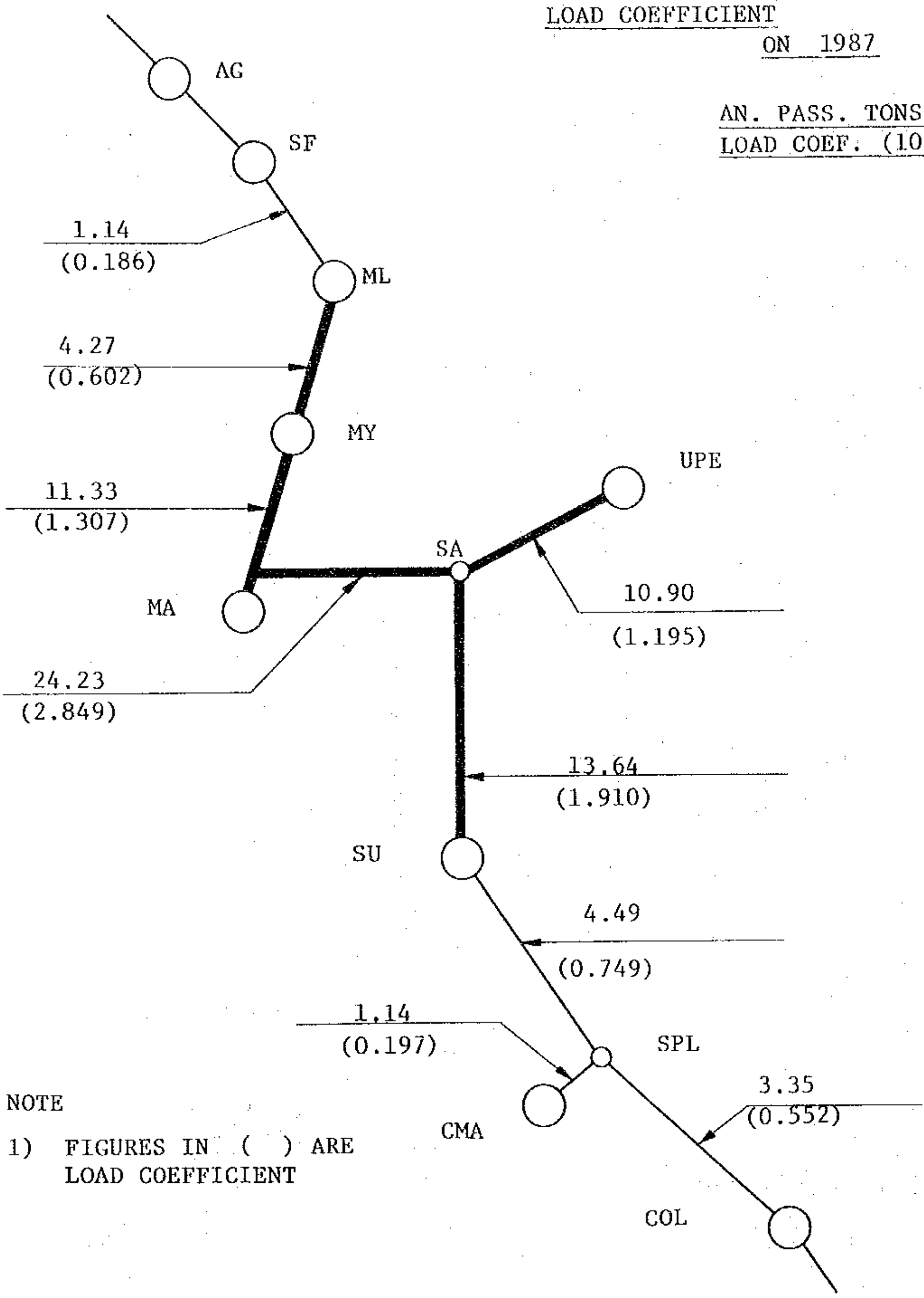

NOTE

1) FIGURES IN ( ) ARE LOAD COEFFICIENT
2) EXCLUDED MANILA TO TAYUMAN"Y"
3) VELOCITY OF BETWEEN SA AND SU IS ADOPTED THE VELOCITY OF BETWEEN PACO AND SU.

Figure 4.3.2

ANNUAL PASSING TONNAGE AND LOAD COEFFICIENT ON 1987

AN. PASS. TONS. (mn tons)
LOAD COEF. (100mn tons.k/h)

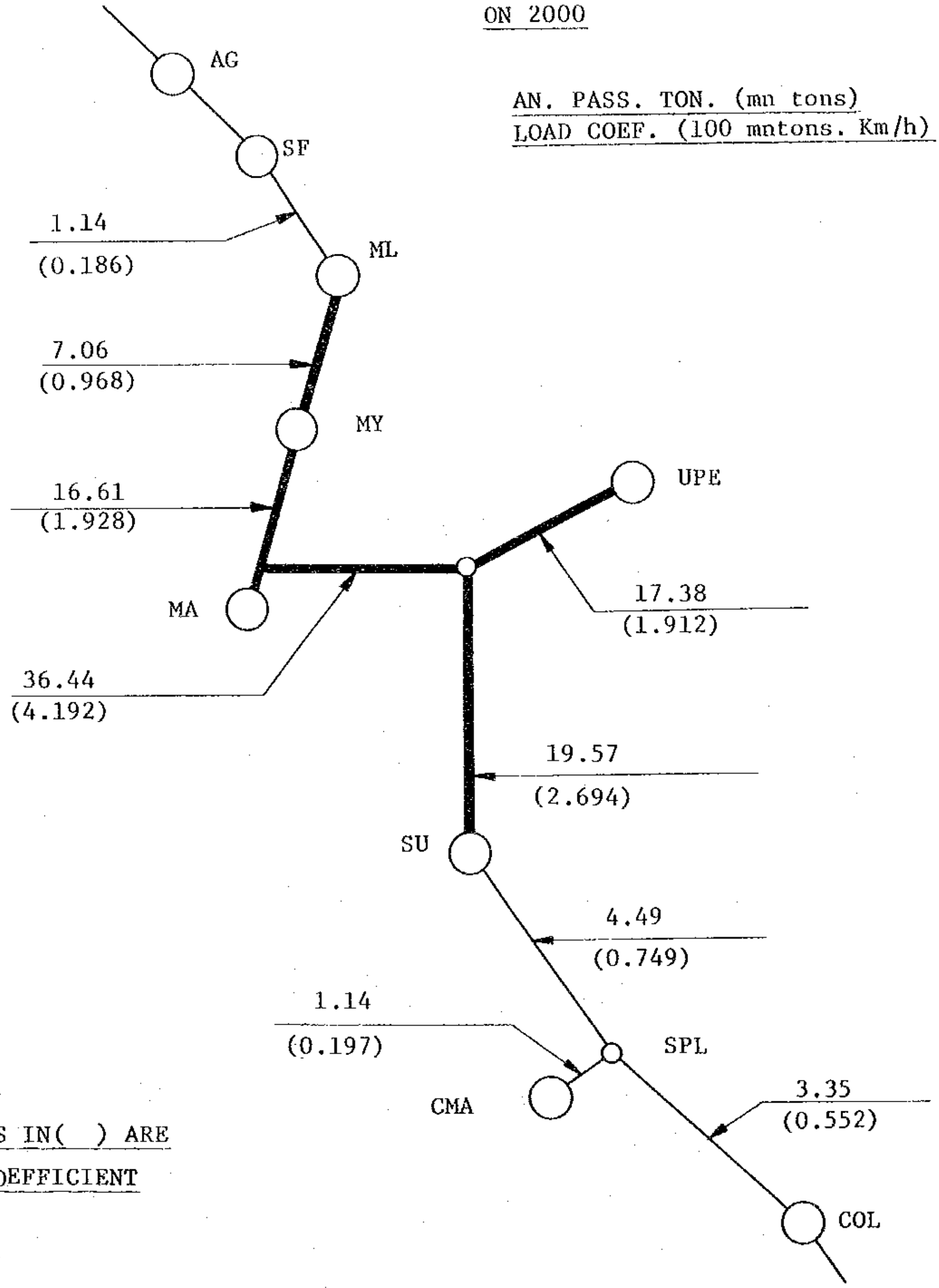



NOTE

1) FIGURES IN ( ) ARE LOAD COEFFICIENT

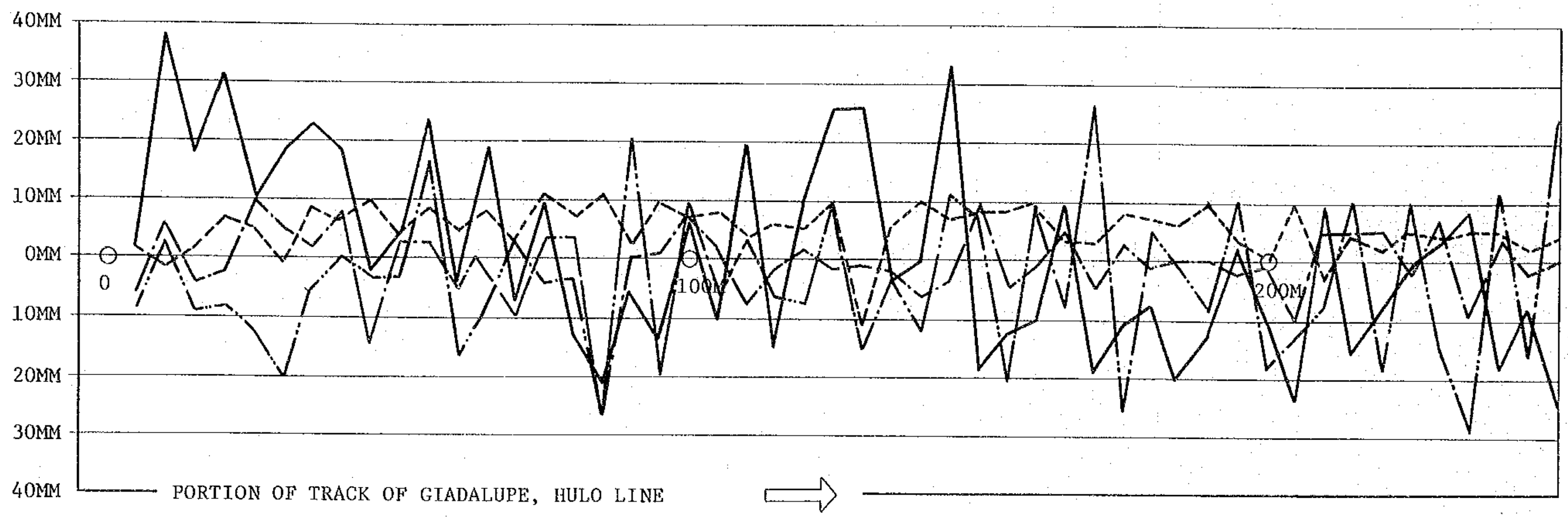
Figure 4.3.3

ANUAL PASSING TONNAGE AND LOAD COEFFICIENT ON 2000




NOTE

1) FIGURES IN( ) ARE LOAD COEFFICIENT




LEGEND

- GAUGE
- CROSS LEVEL
- LONGITUDINAL LEVEL
- ALIGNMENT

SCALE 1CM = 10MM (Vertical)
1CM = 10M (HORIZONTAL)

Fig. 4.4 Present situation of track irregularities of PNR

The structure coefficient, M, for the standard track structure is as shown in Table 4.5.

All these values have been empirically established with respect to the rolling stock used in Japan, but may be applied to PNR's rolling stock which is almost the same as Japan's.

The maintenance volume coefficient, P, is estimated from Japanese examples at 0.53 for not more than 5 mil. tons of annual passing tonnage and 0.7 for 10 to 20 mil. tons. From these values, the number of service workers required per km is calculated as shown in Table 4.6.

At present, PNR has no established track maintenance standards, and the track is deformed bitterly as shown in Fig. 4.4.

This in synergy with the pitching, rolling and yawing of the rolling stock often leads to derailments whose causes are indeterminable. When the train services have been increased, the derailment will develop a serious disaster owing to collision between a derailed train, opposing train, and the trains running just behind them. Thus, the track maintenance standards should be established as soon as possible in order to obviate derailment.

The track irregularity to the extent of causing a car derailment ought to have been heralded by poor riding conditions due to violent shocks and vibration. In other words, the level of track maintenance that assures comfortable riding can automatically prevent derailment.

Changes in riding comfort of passengercars of Japanese make with amount of irregularities of track are as shown in Fig. 4.5. So far as Fig. 4.5 applies, it is evident that the track should be maintained to keep the irregularities of longitudinal level below 8 mm.

Figure 4.5.1

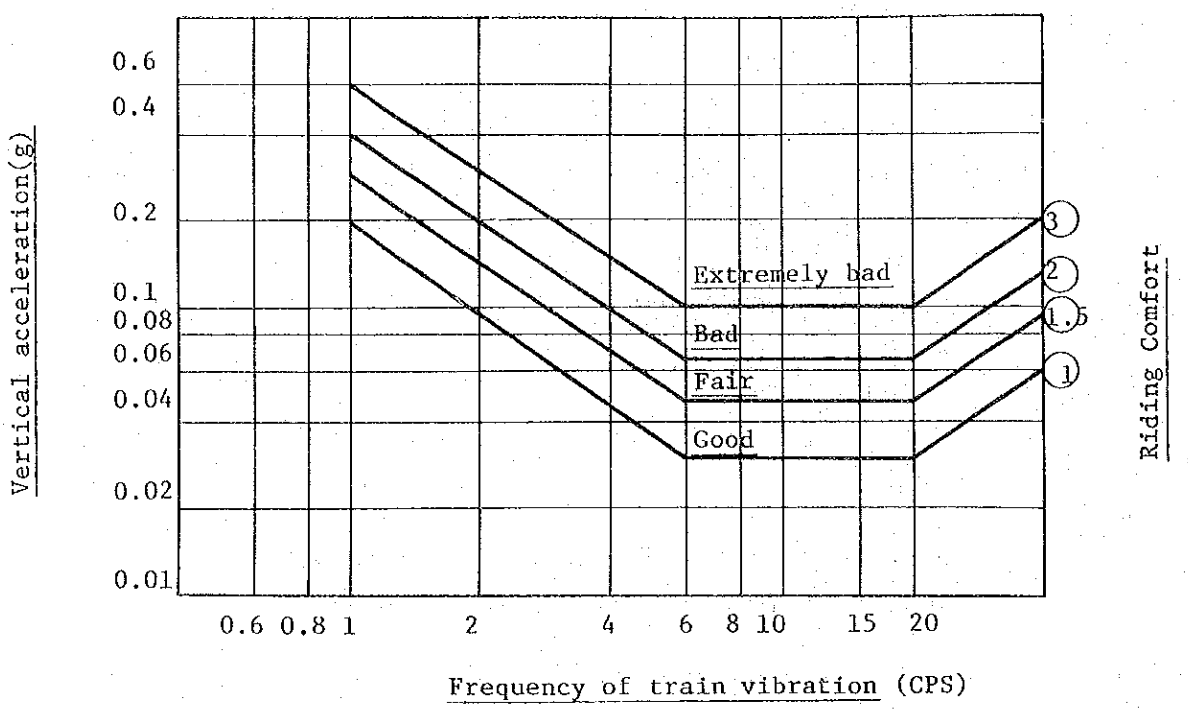



Figure 4.5.2

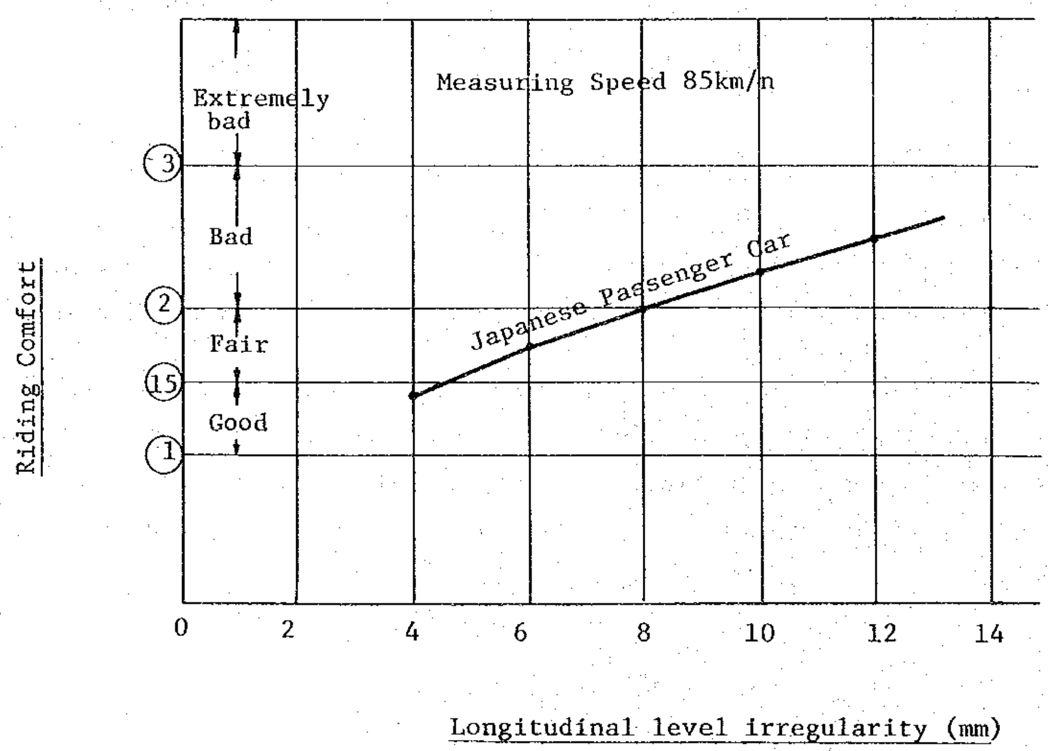


Table 4.5.1 Structure Coefficient of Track

30kg (65 lb) Rail, Crushed Stone Ballast

| Tie spacing / Depth of ballast | 66 cm | 65 cm | 62 cm | 60 cm | 58 cm |
|---|---|---|---|---|---|
| 150 mm | 3.57 | 3.43 | 3.26 | 3.12 | 3.00 |
| 200 mm | 3.21 | 3.17 | 3.00 | 2.89 | 2.78 |

30 kg (65 lb) Rail, Sieved Gravel Ballast

| Tie spacing / Depth of ballast | 66 cm | 65 cm | 62 cm | 60 cm | 58 cm |
|---|---|---|---|---|---|
| 150 mm | 5.57 | 5.35 | 5.08 | 4.87 | 4.68 |
| 200 mm | 5.00 | 4.95 | 4.68 | 4.51 | 4.34 |

Note

1. Tie spacing is the distance between two sleeper except at the joint.

2. Depth of ballast is the distance between bottom of sleeper and road surface at under the rail.

Table 4.5.2 Structure Coefficient of Track

37 kg (75 lb) Rail, Crushed Stone Ballast

| Tie spacing / Depth of ballast | 66 cm | 65 cm | 62 cm | 60 cm | 58 cm |
|---|---|---|---|---|---|
| 150 mm | 2.50 | 2.47 | 2.32 | 2.25 | 2.16 |
| 200 mm | 2.32 | 2.29 | 2.14 | 2.08 | 1.99 |
| 250 mm | 2.14 | 2.11 | 1.98 | 1.92 | 1.83 |

37 kg (75 lb) Rail, Sieved Gravel Ballast

| Tie spacing / Depth of ballast | 66 cm | 65 cm | 62 cm | 60 cm | 58 cm |
|---|---|---|---|---|---|
| 150 mm | 3.90 | 3.85 | 3.62 | 3.51 | 3.37 |
| 200 mm | 3.62 | 3.57 | 3.34 | 3.24 | 3.10 |
| 250 mm | 3.34 | 3.29 | 3.09 | 3.00 | 2.85 |

Table 4.5.3 Structure Coefficient of Track

50N Rail, Crushed Stone Ballast

| Depth of ballast \ Tie spacing | 66 cm | 65 cm | 62 cm | 60 cm | 58 cm |
|---|---|---|---|---|---|
| 150 mm | 1.48 | 1.46 | 1.38 | 1.32 | |
| 200 mm | 1.36 | 1.35 | 1.28 | 1.23 | 1.16 |
| 250 mm | 1.26 | 1.25 | 1.18 | 1.13 | 1.07 |

50N Rail, Sieved Gravel Ballast

| Depth of ballast \ Tie spacing | 66 cm | 65 cm | 62 cm | 60 cm | 58 cm |
|---|---|---|---|---|---|
| 150 mm | 2.31 | 2.28 | 2.15 | 2.06 | |
| 200 mm | 2.12 | 2.11 | 2.00 | 1.92 | 1.81 |
| 250 mm | 1.97 | 1.95 | 1.84 | 1.76 | 1.67 |

Table 4.6 Maintenance crew requirements when track is not strengthened

| Section | Present | 1987 | 2000 |
|---|---|---|---|
| ML-CN | 0.808 | 1.087 | 1.310 |
| CN-MA | 0.782 | 1.560 | 1.951 |
| MA-SA | 0.818 | 1.931 | 2.517 |
| SA-UPE | 0.748 | 1.503 | 1.965 |
| SA-SU | 0.821 | 1.467 | 1.779 |

(Tamping workers/km)

Table 4.7.1 Aggregate length of track tamping work for ensuring good riding comfort

| Section | Present | 1987 | 2000 |
|---|---|---|---|
| ML-CN | 713 m | 2,672 m | 4,419 m |
| CN-MA | 751 m | 7,087 m | 10,400 m |
| MA-SA | 283 m | 2,714 m | 4,078 m |
| SA-UPE | 250 m | 6,822 m | 1,086 m |
| SA-SU | 238 m | 1,527 m | 2,191 m |

(Annual tamping meters per km of aggregate track length)

Table 4.7.2 Aggregate length of track tamping work necessary for ensuring good riding comfort (in case of strengthened track)

| Section | Present | 1987 | 2000 |
|---|---|---|---|
| ML-CN | | 478 m | 790 m |
| CN-MA | | 1,269 m | 1,859 m |
| MA-SA | | 1,283 m | 1,929 m |
| SA-UPE | | 1,220 m | 1,946 m |
| SA-SU | | 722 m | 1,036 m |

(Annual tamping meters per km of aggregate track length)

Table 4.7.3 Maintenance crew requirements after track strengthening

| Section | Present | 1987 | 2000 |
|---|---|---|---|
| ML-CN | | 0.962 | 1.107 |
| CN-MA | | 1.286 | 1.548 |
| MA-SA | | 1.672 | 2.136 |
| SA-UPE | | 1.253 | 1.565 |
| SA-SU | | 1.294 | 1.533 |

(Tamping workers/km)

Assuming that the longitudinal level irregularities should be held within 8 mm by track maintenance, the maintenance volume is calculated to determine how to improve the track structure.

Of the track maintenance jobs, the one that necessitates labor most is ballast tamping work. To facilitate the track maintenance work, the tamping cycle should preferably be more than 180 days.

The tamping cycle, T, is given by the following empirical formula.

$$T = \frac{Ylim^2 - 31.67}{0.001907\ W \cdot e^{0.72M}}$$

Where, T: tamping cycle (days)

W: annual passing tonnage (mil. tons)

e: Euler's constant

M: structure coefficient

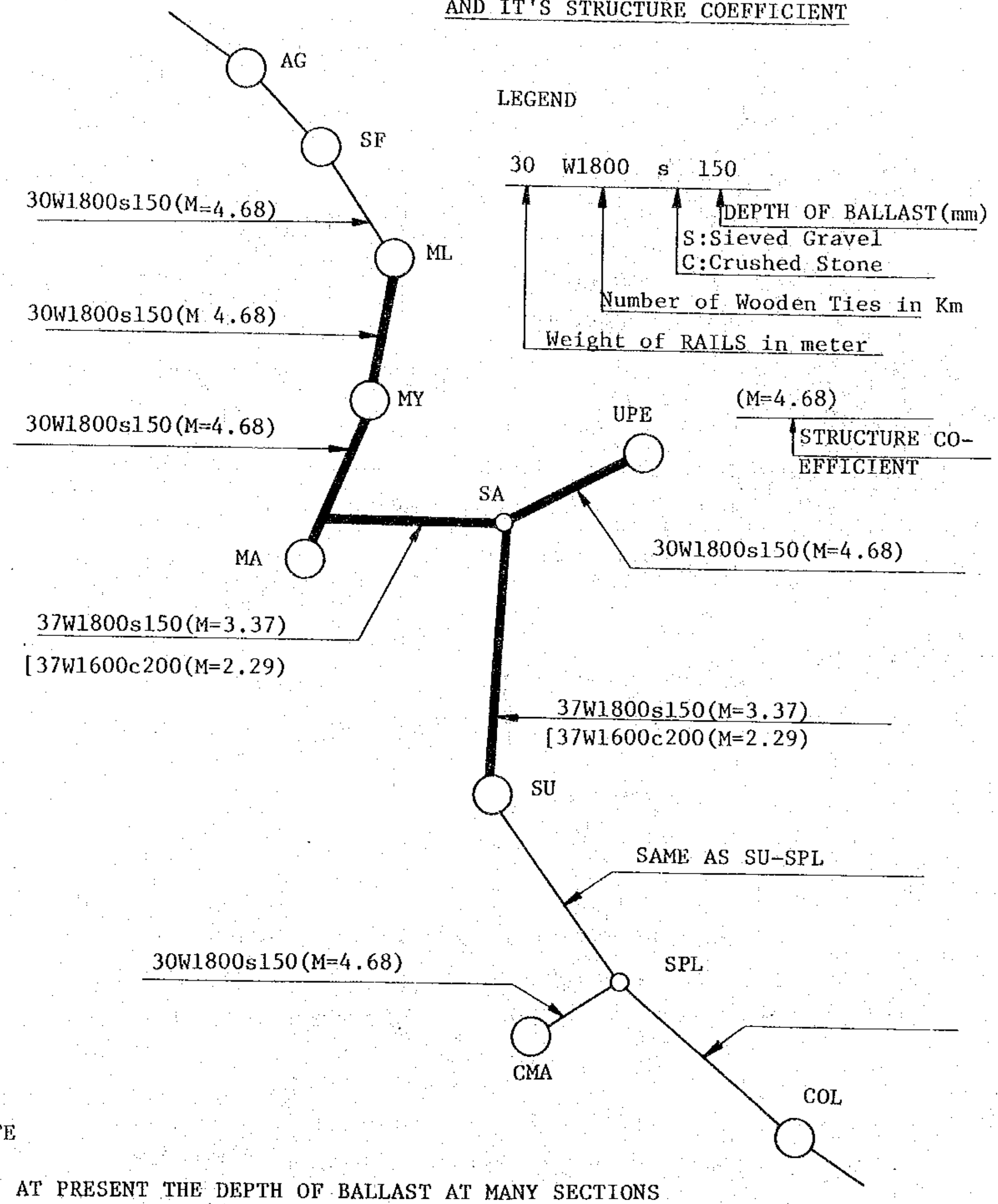
If the formula above is applied to PNR's track conditions, the tamping cylces are determined as shown in Table 4.7. Thus, it is recommended to replace the Malolos-Manila section and the Sta. Mesa-Guadlupe section with 37-kg rails and the Manila-Sta. Mesa section with 50-kg rails by the year 1987.

By 2000, it is recommended to replace the Sta. Mesa-Sucat section with 50-kg rails.

All these circumstances are illustrated in Fig. 4.6.

Figure 4.6.1

TRACK STRUCTURE (PRESENT TIME)
AND IT'S STRUCTURE COEFFICIENT



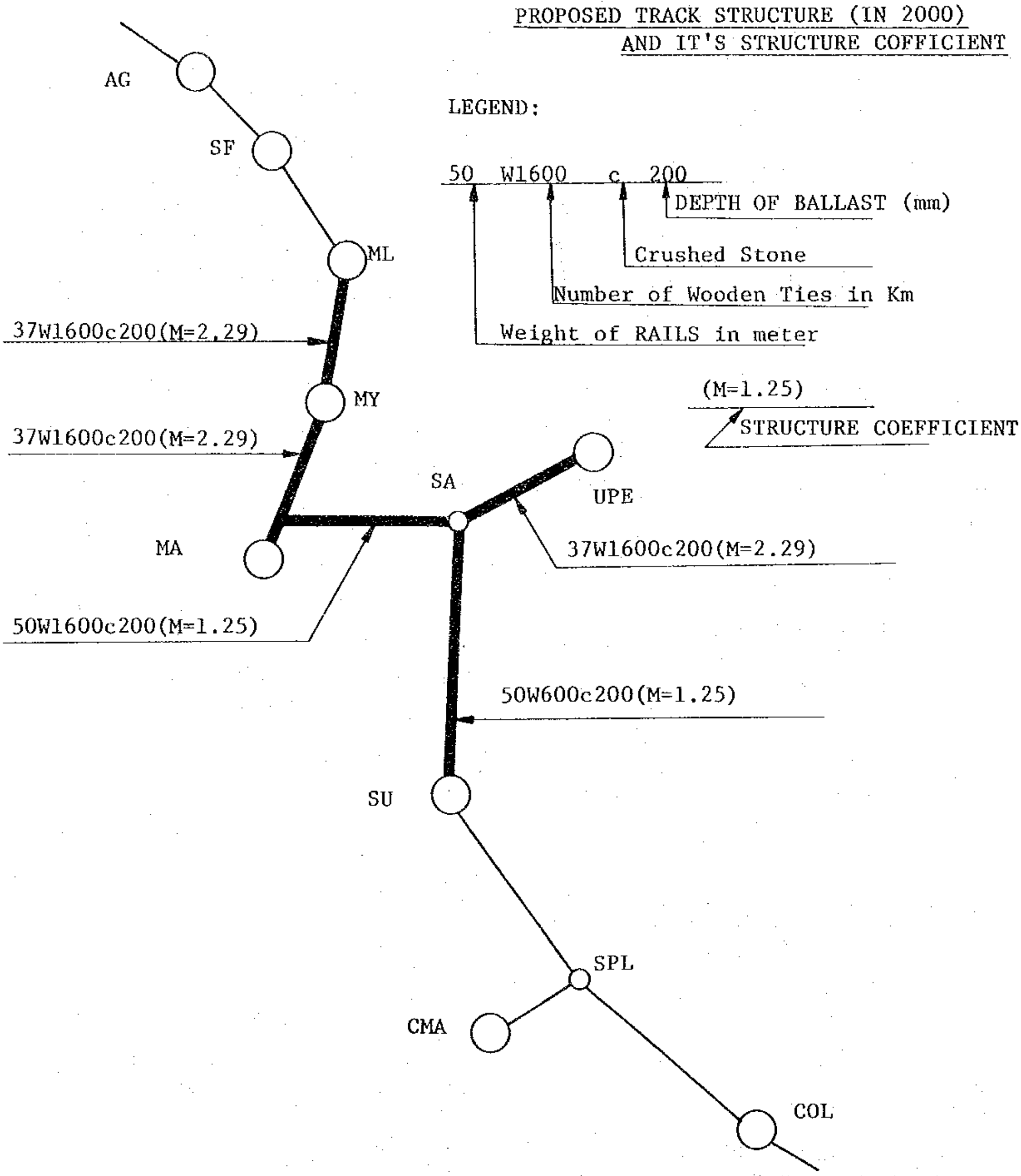

NOTE

1. AT PRESENT THE DEPTH OF BALLAST AT MANY SECTIONS ARE UNDER 150mm.

2. FIGURE IN THE ( ) ARE AFTER REHABILITATIONS OF ADB PROJECT.

Figure 4.6.2

PROPOSED TRACK STRUCTURE (IN 2000)
AND IT'S STRUCTURE COFFICIENT



With increase in the number of trains, the rails will be worn out increasingly. In order to check the wear of rails, the following measures are recommended.

(1) To use head-hardened rails.

(2) To use high-carbon rails of high hardness.

(3) To use the rails whose head goes well with the wear conditions of the wheels.

To satisfy these requirements, 40N and 50N rails are specially designed and available for effectively reducing the rail wear.

In order to make the most of excellent acceleration and deceleration characteristics the electric car has, anticreeping measures should be taken for the rails. Namely, use of elastic fastening, anti-creeepers and/or anti-creeping stakes should be considered.

The elastic fastening is available in the following three methods.

(1) Use of spring spike.

(2) Use of spring clip and bolt in combination.

(3) Use of special spring.

Although the spring spike is the cheapest, it gets loose when the cross ties rot. The spring clip method is compratively inexpensive, but its fastening force is hard to maintain. Also, there is a fear that it is easily robbed of or tampered with. Pandrol used in U.K. and other special springs are costly though they are free of these defects.

To stick to a happy medium, it may be acceptable to use spring spikes for the time being and replace them with Pandrol or spring clips in future.

Where the creeping is noticeable, anti-creepers should be installed according to the following standard.

Table 4.9

| Grade | up to 5,1,000 | 5/1,000 ∿ 10/1,000 | 10/1,000 ∿ 15/1,000 | 15/1,000 ∿ 20/1,000 | 20/1,000 ∿ 25/1,000 |
|---|---|---|---|---|---|
| Number of anti-creepers per 10 m | 8 | 8 | 14 | 18 | 22 |

Once the electrification work has been completed, the contact wire level must be adjusted every time when the rail height is changed. For this reason, the following work should be completed before electrification work.

(1) To reconstruct the ballast to have a required depth.

(2) To adjust the cant to a specified value.

(3) To replace the rails with heavy ones.

All these operations are necessary for the purpose of reinforcing the transport capacity, and are not limited to electrification work alone.

For the electrification work, the following will be necessary.

(1) Anti-creepers, and spring clips for elastic fastening.

# 5. Engineering Considerations

## 5-1 Electric Power Situation

In the Philippines, the National Power Corporation (NPC) is in charge of generation, transmission and transformation, and the distribution alone is undertaken by local power companies. For Metro Manila and its satellite cities and towns, however, the Manila Electric Compnay (MERALCO) is undertaking all the power services from generation to distribution.

### 5-1-1 Outlook for electric power demand and supply

The railway electrification depends heavily on the availability of electric power. In Luzon, NPC's electric power system is interconnected to MERALCO's. The demand and supply conditions in future should therefore be studied not only on MERALCO which is to serve the railways direct, but also on NPC.

Figs. 5-1 and 5-2 show a forecast by generating system of peak demand, generating capacity and energy requirement in the future Luzon according to the data released by NPC. At present, 75 to 85% of the total generating capacity and generated output are accounted for by thermal power plants, and the remainder by the hydroelectric. For the year 1987, it is likely that hydroelectric, geothermal, atomic and oil-fired thermal power plants will account for 41%, 10%, 9% and 40% of total supply, respectively.

The generating capacity in 1978 is expected to be about 2,500 MW to have an allowance of some 20% as against 2,000 MW of peak demand. Although few oil-fired thermal power plants will be installed in future, hydroelectirc, geothermal and atomic power plants are planned to be constructed one after another, and the supply allowance in each of the years to come is expected to be 20 to 30%. In 1987, the generating capacity is expected to be 6,500 MW to have an allowance of 28% as against a peak demand of 4,700 MW.

In 1978, the generated output is 12,000 mil. kWh as against a demand of 11,700 mil. kWh, leaving as small a margin as 2.7%. From next year on, however, the allowance is expected to rise to 8 to 19%. As discussed later on, the train operation requires some 13 MW or 70 mil. kWh a year, and there will be no problem so far as electric power supply to railways is concerned.

FIG. 5-1 PEAK DEMAND AND CAPACITY IN LUZON POWER GRID

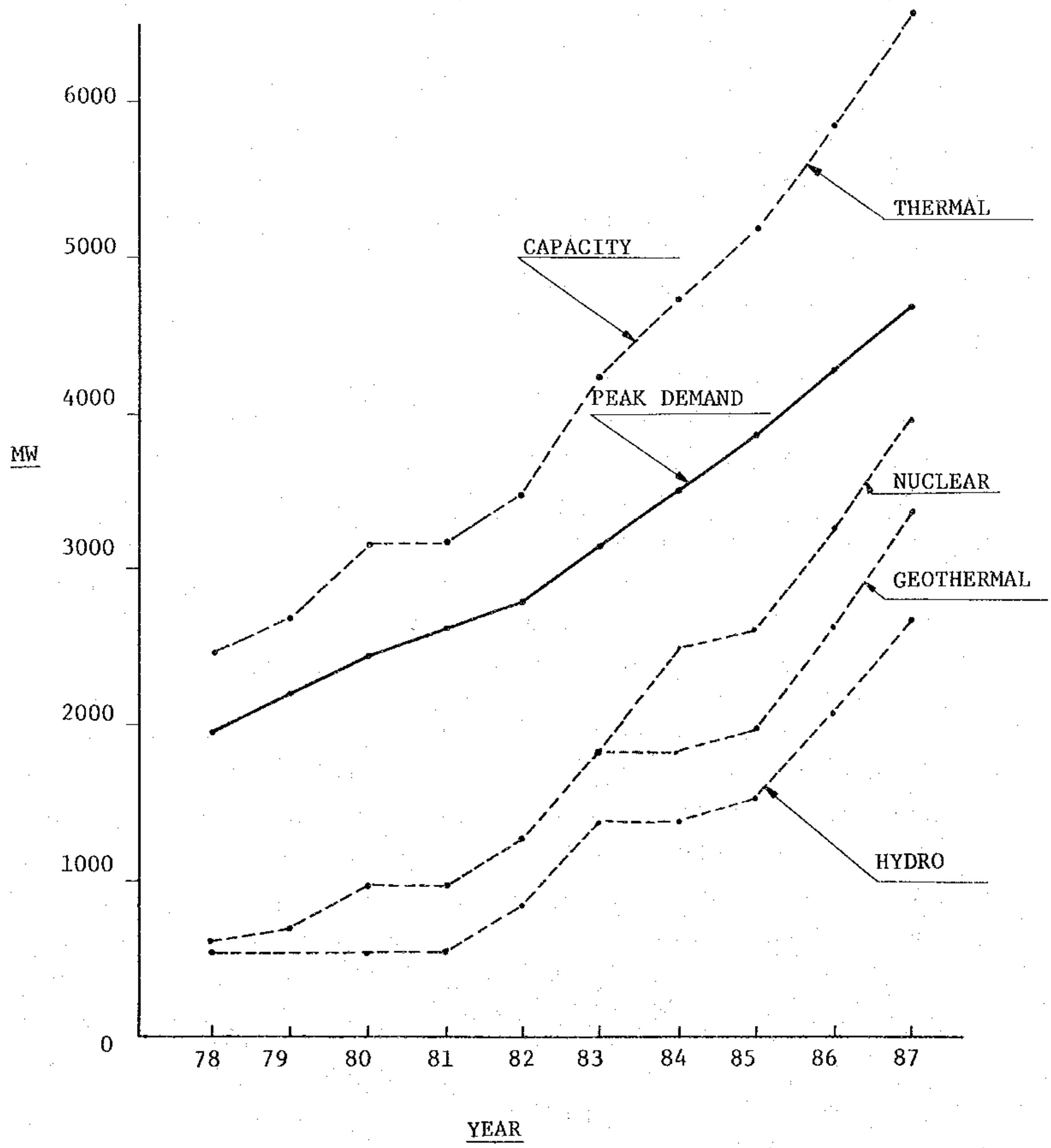
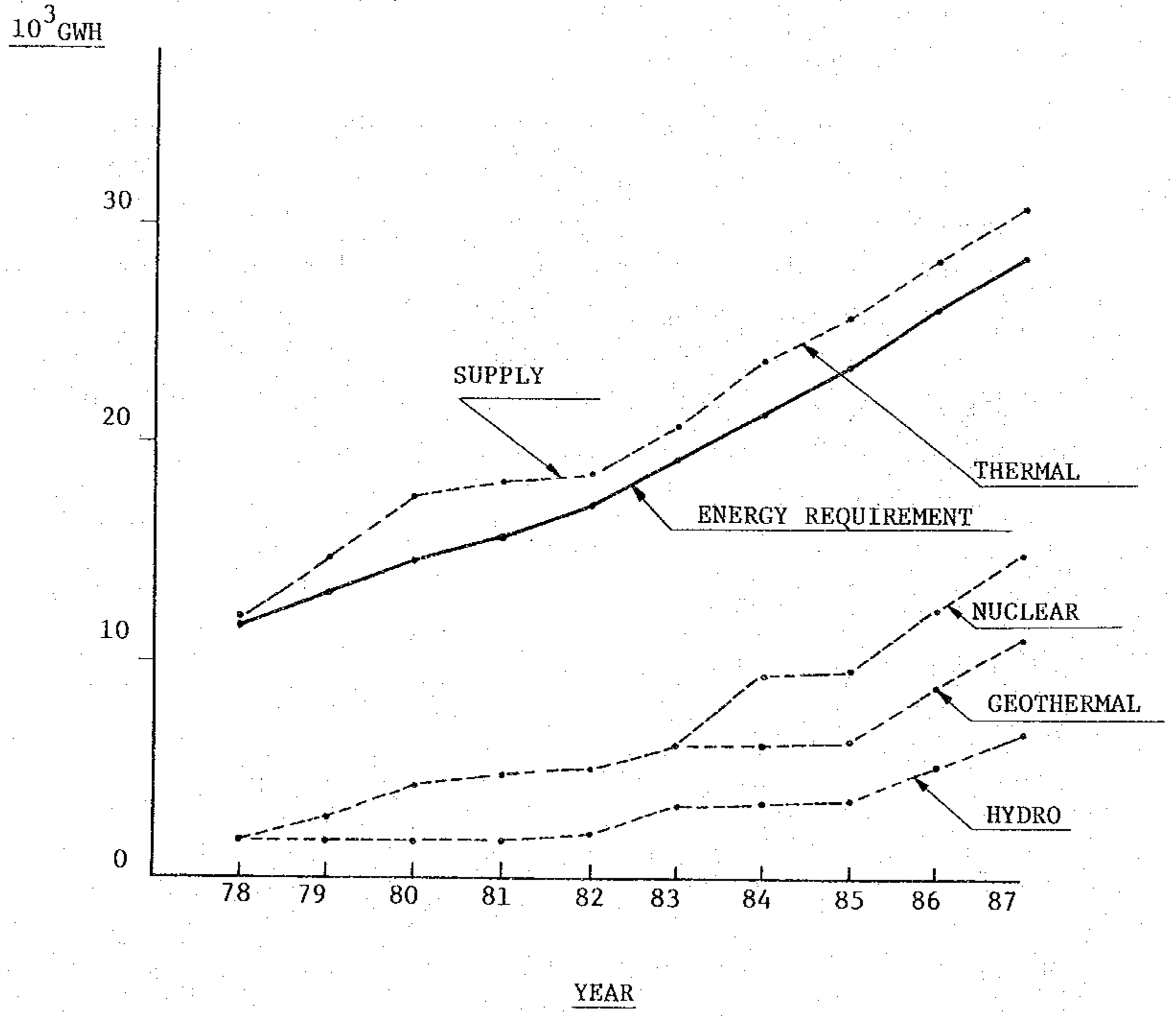


FIG. 5-2 ENERGY REQUIREMENT AND SUPPLY IN LUZON POWER GRID



## 5-1-2 Power network

Fig. 5-3 illustrates a power network for the commuter service electrification project, which is composed mainly of 115 kV transmission lines owned by MERALCO.

Fig. 5-4 shows a geography of railways, stations, MERALCO's power plants, substations and transmission lines, all concerned with the project.

MERALCO's power network is composed of transmission grids of 115 kV and distribution grids of 34.5 kV and lower. MERALCO has power plants at Tegen, Rockwell and Gardner. MERALCO's system is interconnected to NPC's at Balintawak and Novaliches substations. The 115 kV transmission grids form a loop, and a failure of one member of the loop can be backed up by the other member for no-break power service. The 115 kV substations and transmission lines and 34.5 kV distribution lines are located near roads and railways.

FIG. 5-3 OUTLINE OF POWER NETWORK

LEGEND

230 KV TRANSMISSION LINE

115 KV TRANSMISSION LINE

34.5 KV TRANSMISSION LINE

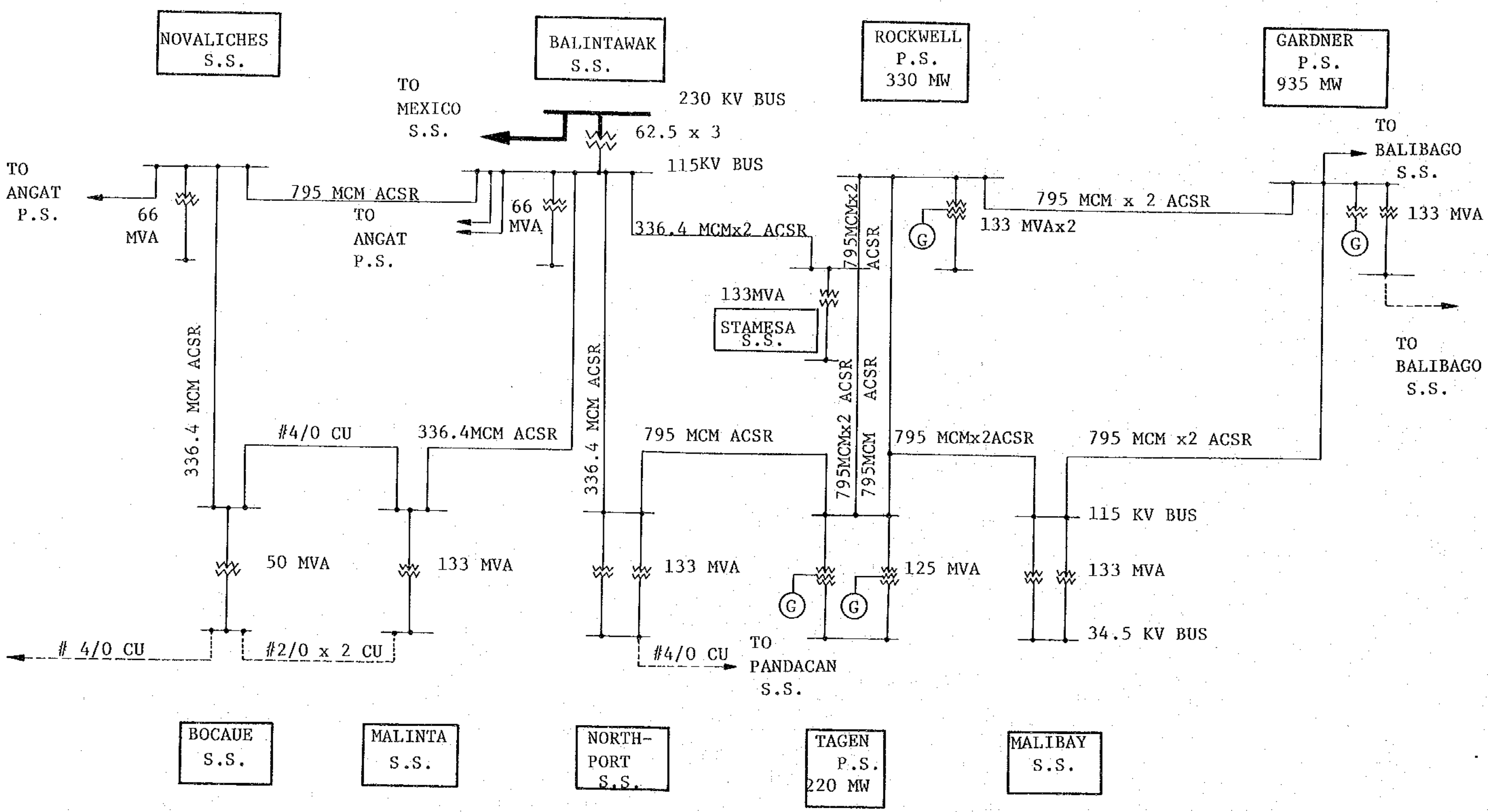
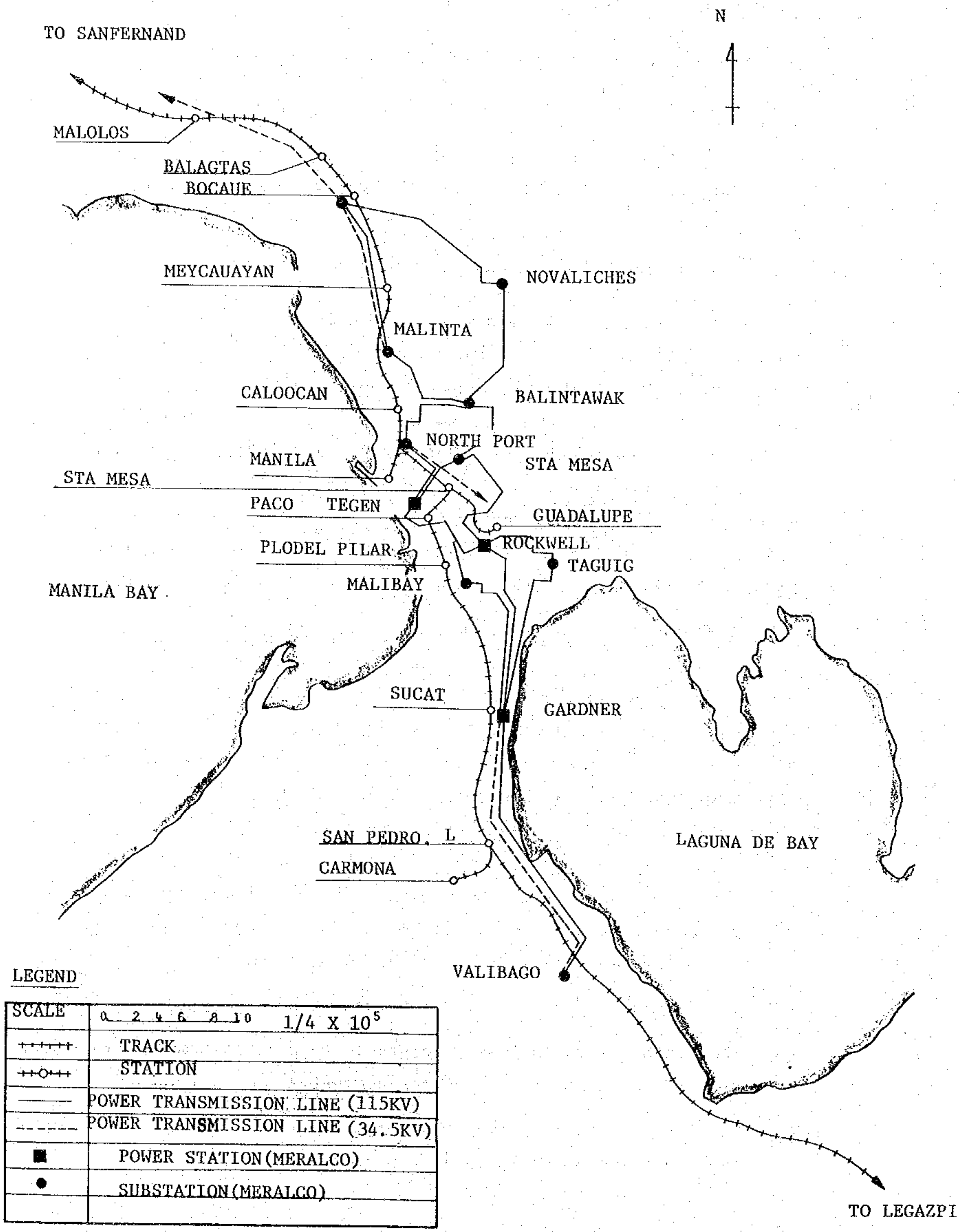


FIG. 5-4 POWER NETWORK IN COMMUTER SERVICE AREA



## 5-2 System of Electrification

The system of railway electrification is classified as follows.

DC system

AC system - Single phase - Commercial frequency (50 or 60 Hz)
Special frequency (16-2/3 or 25 Hz)

AC system - Three phase

The electrification systems most widely accepted in the world for rapid mass transit railways are DC system (1,500 V or 3,000 V), single-phase AC commercial frequency system and single-phase AC special frequency system. Of the two AC system, the single-phase AC commercial frequency system has become prevailing in recent years. The single-phase AC special frequency system necessitates a special generator or a frequency converter for exclusive use with the railway, and is limited to some parts of West Germany, Switzerland, Austria, Norway, Sweden, U.S.A. etc. where it was employed in the past.

Whether DC system or single-phase AC commercial frequency system should be adopted is the crux of the project.

Table 5-1 shows a comparison between DC system (1,500 V) and single-phase AC commercial frequency system. The merits and demerits of the AC system are as enumerated below.

Merits

(1) The costs for construction of transmission lines, substations and overhead contact wire facilities are much cheaper than those for DC system. (See Chap. 6 "CONSTRUCTION COSTS")

(2) The feeding circuit can be protected with ease.

(3) The contact wire is less susceptible to wear as compared with DC system, and least calls for replacement.

(4) The future extension into the neighboring areas can be accomplished more economically than DC system.

Demerits

(1) If the railway is powered from a substation operated marginally, it is likely to affect other users because of voltage unbalance and fluctuations.

(2) PNR's signalling system installed last year is available to DC system, but not to the AC system, and has to be modified.

(3) The telecommunication lines along the railways will be affected by induction interference, and have to be replaced with shielded cables.

(4) Because of high feeding voltage, the insulating clearance between railways and their adjacent structures has to be made greater than in the DC system.

(5) AC electric car is 10 to 20% higher in price than DC one.

Each system has merits and demerits as explained above, and JNR uses both AC and DC systems. Accordingly, the cars running between these two different systems are of the AC-DC dual purpose type. Employment of AC-DC dual cars poses problems in that costly cars are required and that the substations located at the both sides of AC-DC junction point must be fortified since the substations for one system cannot feed another system. For PNR, electrification is a new experience. To make a good start, in-depth studies and investigations should be conducted before choosing between the two systems. The discussions in this report are therefore limited to the comparison of AC and DC systems from the viewpoint of engineering without favor or prejudice.

Table 5-1 AC Electrification vs. DC Electrification comparison

| Item | AC system (60 Hz, single-phase, 25 kV) | DC system (1.5 kV) |
| --- | --- | --- |
| I. Ground facilities | | |
| 1. Installations | | |
| (1) Transmission lines | Traction substations can be located with a high degree of freedom over a comparatively wide area. AC system requires a less number of traction substations than DC system, and its transmission lines cost less than DC system's.<br>Where the capacity of the power supply is not enough, voltage unbalance and fluctuations may affect other users. | Traction substations are required to be installed within a comparatively narrow area. DC system necessitates a good number of traction substations, sending up the construction costs for its transmission lines.<br>The construction of transmission lines may be hampered by the problems concerning environments and right-of-way depending on location. |
| (2) Traction substation | The construction cost for traction substation is by for lower than DC system's.<br>1. Usually, the spacing between traction substations can be made as long as 30 to 40 km (for BT system), 60 to 80 km (for AT system), making it possible to reduce the number of traction substations.<br>2. AC traction substation is simple in arrangements; its major equipment is limited to transformer, switches, etc. | The construction cost is by far higher than AC system's.<br>1. Usually, the spacing between traction substations is 5 to 15 km.<br>2. DC traction substation uses transformer, rectifier, AC and DC switches, and is somewhat complicated. |

| Item | AC system (60 Hz, single-phase, 25 kV) | DC system (1.5 kV) |
|---|---|---|
| (3) Contact wire system | The load current is small, and the conductor size can be small. The construction costs for the contact wire system are smaller than DC system. | The load current is far and away larger than AC system; the size of the feeder must be 10 times as much as that for AT system. |
| (4) Signalling system (track circuit) | Frequency divider and doubler or AF track circuit is needed. | AC commercial frequency track circuit can be used. |
| (5) Telecommunication | The nearby communication lines are seriously affected by induction interference, and it is required to install BT or AT and shield the bare conductors by employing cables. | Induction interference with communication lines is less, and there is no need of installing special equipment except for filters at traction substations. |
| 2. System | | |
| (1) Measures against voltage drop | The voltage drop expected to be developed when the load is increased in future can easily be compensated by installing series capacitors and voltage regulators. | It is necessary to install additional feeders, traction substations or sectioning posts. |
| (2) Insulation clearance | The feeder voltage is high, and the insulation clearance must be larger than DC system's. Usually, the cross section of tunnel must be made a little larger than DC system's. | The feeder voltage is low, and the insulation clearance can be small. |
| (3) Protection | The differences between load current and fault current in phase angle and amplitude are large, and the discrimination of them is easly.<br>Fault point can be easily find out by fault locator. | The load current is very large, and the discrimination of load current and fault current from each other is made by detecting the current increment ΔI.<br>For the purpose of enhancing protection reliability, interlinked breaking device, etc. are necessary, making |

| Item | AC system (60 Hz, single-phase, 25 kV) | DC system (1.5 kV) |
|---|---|---|
| | | the protective system more complicated than in AC system. |
| (4) Electrolytic corrosion | No fear of electrolytic corrosion. | Where the rail leakage resistance is small, electrolytic corrosion due to leakage DC current might happen. |
| (5) Energy efficiency | The loss in the contact wire system is less, and the overall energy efficiency is a little higher than in DC system. | |
| 3. Maintenance | | |
| (1) Traction substation | The number of traction substations is smaller, and the facilities are simpler, making the maintenance easier. | Calls for much maintenance efforts. |
| (2) Contact wire facilities | The contact wire current is smaller, and the contact wire wear is less. Little or no replacement of contact wire will be needed.<br>Because of high feeder voltage, hot-line maintenance work is difficult. | The contact wire wears away easily, and must be renewed every 5 to 10 years, sending up the maintenance costs extremely.<br>Hot-line maintenance work is possible. |
| 4. Others | | |
| (1) Train operation | Usually, dead section is required.<br>This puts the operator to some trouble because he must cut off the motor there for coasting. | No dead section is required. |

| Item | AC system (60 Hz, single-phase, 25 kV) | DC system (1.5 kV) |
|---|---|---|
| (2) Expansion work | Usually, economically done. | Costs much. In DC electrified section is expanded with AC system, AC-DC dual purpose cars are required, sending up the rolling stock costs. AC traction substation cannot feed DC section, and vice versa. Thus, traction substations located at the AC-DC junction point must be reinforced. |
| (3) Trackage-right operation | If a subway of DC system is to be used, AC-DC dual purpose cars are necessary. | Trackage-right operation is easy if both systems have the same feeder voltage. |
| II. Rolling stock | | |
| 1. Facilities | | |
| (1) Transformer and converter | Transformer and rectifier are to be carried on board a car. The car carrying these is several tons heavier. | |
| (2) Auxiliaries | Simple, sturdy induction motor can be employed. The power supply facility for fluorescent lights and air conditioner is simple. | Complicated DC motor is necessary. Motor-generator set is necessary for controls, fluorescent lights, and air conditioner. |

| Item | AC system (60 Hz, single-phase, 25 kV) | DC system (1.5 kV) |
|---|---|---|
| 2. System | | |
| (1) Speed control | Speed can easily be controlled by changing transformer tap position or by phase-controlled thyristor. | In the case of rheostatic control car, the speed is controlled by adjusting resistors and changing the motor connections. This scheme is somewhat complicated. Starting power consumption is much. |
| 3. Maintenance | Transformer and rectifier are static equipment, and their maintenance calls for not so much labor. | Maintenance is easy. |
| 4. Rolling stock cost | AC car is 10 to 20% higher in cost than DC car. | Not expensive. |

## 5-3 Master Plan for AC Electrification

The single-phase AC commercial frequency system is classified in many feeding systems. Of them, the most typical feeding systems are illustrated in Fig. 5-5. PNR's railways are running through the centers of major cities, and the simple feeding system (Fig. A), the simplest and cheapest of all, cannot be applied because of no measures against induction interference with telecommunication lines.
The AT system (auto transformer system) (Fig. B) in which JNR has much experience and the BT system (booster transformer system) (Fig. C) are provided with measures against induction interference.
Of these two, the AT system is better because it is high in reliability and easy in maintenance.

Fig. 5-6 shows an AT power feeding system, and Fig. 5-7 the location of traction substations for it.

FIG. 5-5 TYPICAL FEEDING SYSTEM OF A.C. ELECTIFICATION

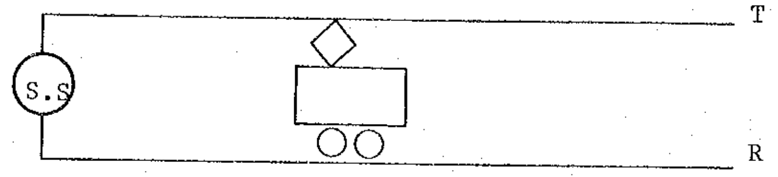



FIG. A SIMPLE FEEDING SYSTEM

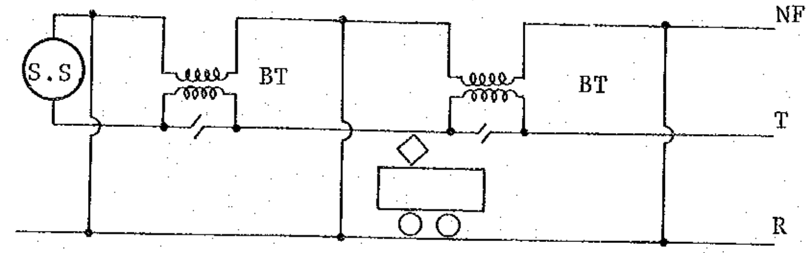



FIG. C BT FEEDING SYSTEM

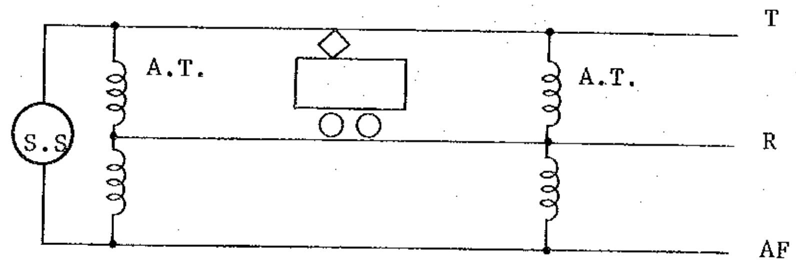



FIG. B A.T. FEEDING SYSTEM

LEGEND

| | |
|---|---|
| S.S. | TRACTION SUBSTATION |
| A.T. | AUTO TRANSFORMER |
| B.T. | BOOSTER TRANSFORMER |
| T | CONTACT WIRE |
| R | RAIL |
| A.F. | AT FEEDER |
| N.F. | NEGATIVE FEEDER |

FIG. 5-6 ELECTRIC POWER FEEDING SYSTEM (AC. SYSTEM)

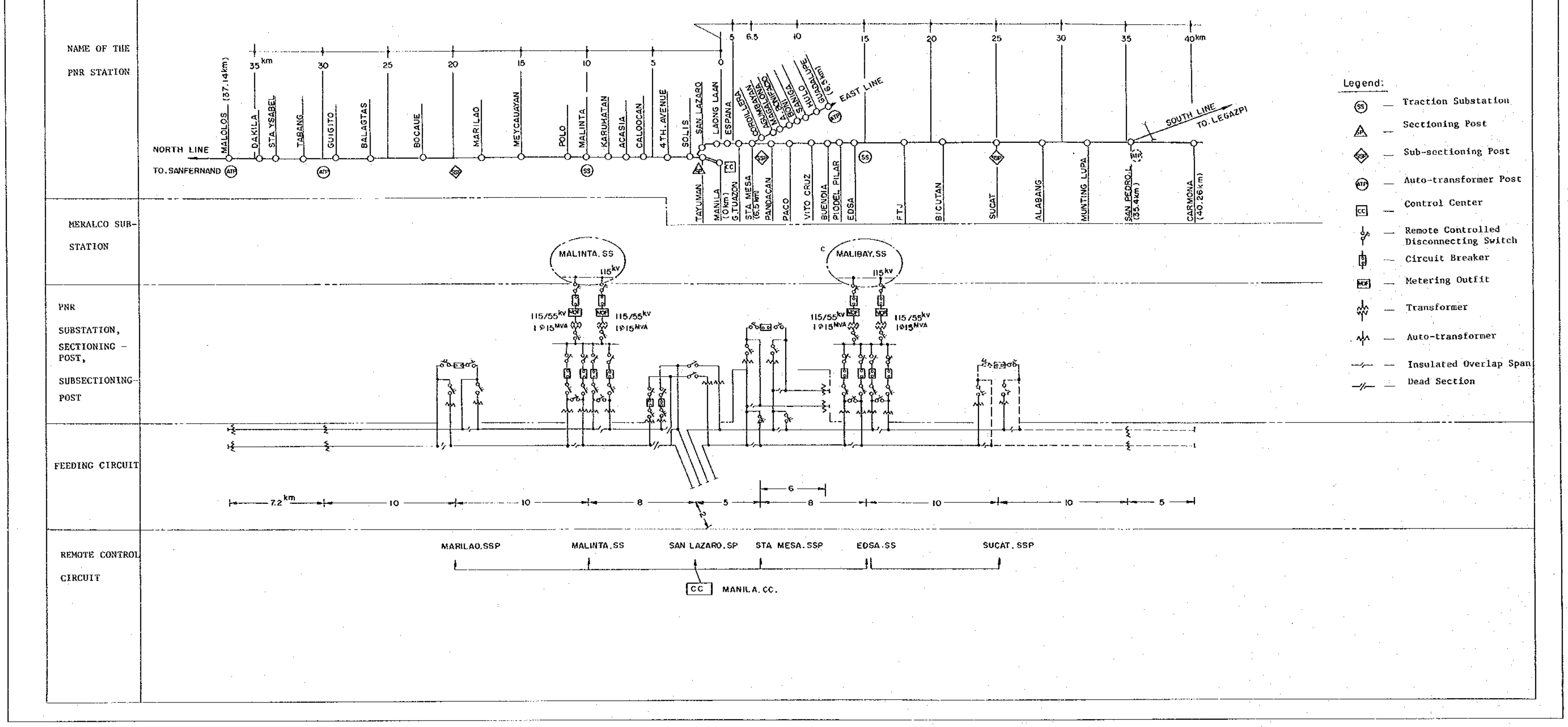
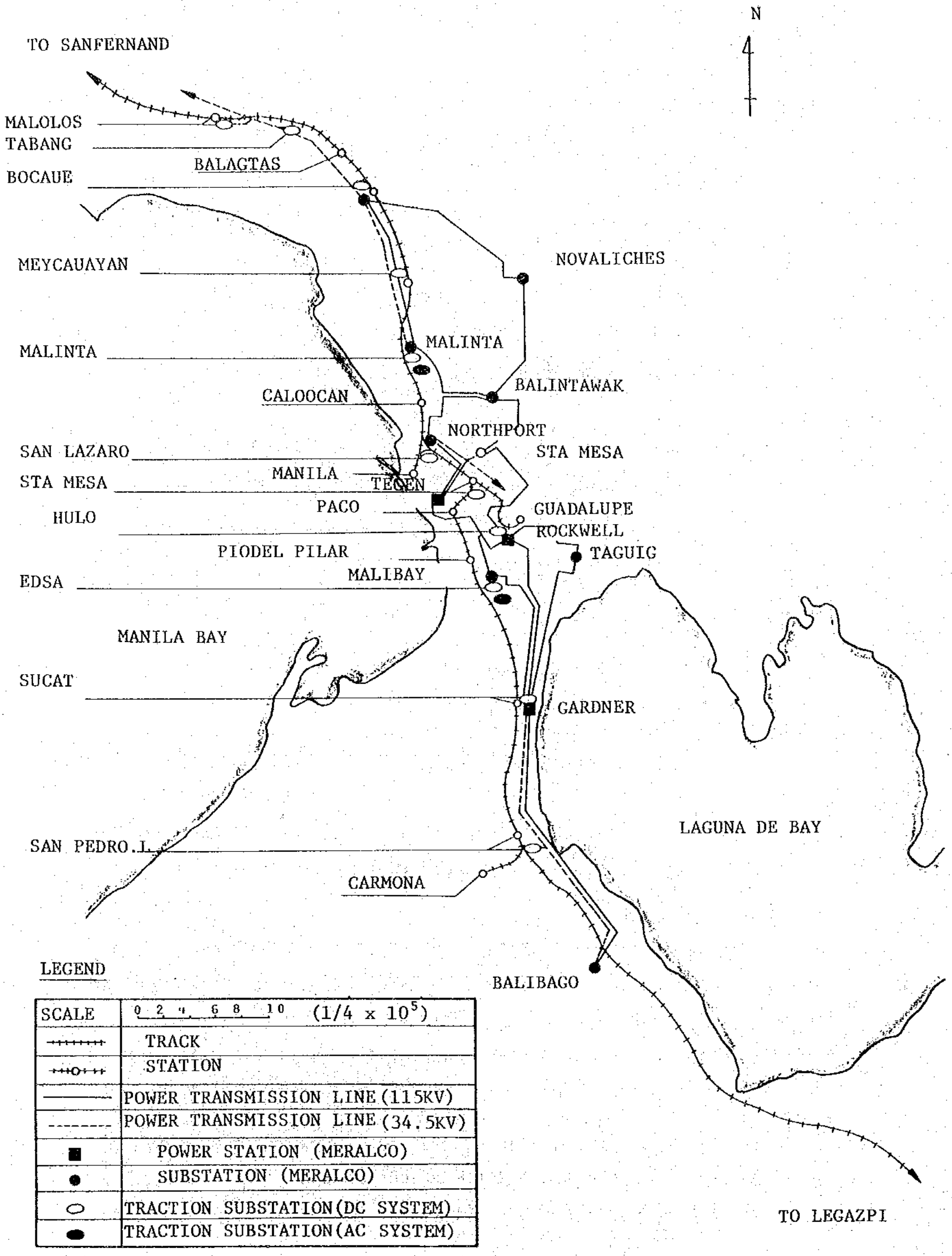


FIG. 5-7 LOCATION OF TRACTION SUBSTATION



### 5-3-1 Concepts of power feeding system, and location of traction substations

What must be reckoned with in planning a power feeding system and its facilities includes these:

(1) Ability to supply high-quality electricity in a reliable way (i.e., electricity of stabilized voltage and of least vulnerable to blackout failure).

(2) Protection of general users from evil effects resulting from railway electrification.

(3) Protection of telecommunication lines from induction interference.

(4) Ability to instantaneously interrupt power supply to defective circuits subjected to, for example, ground fault.

(5) Protection of electric railway facilities from vital damage due to natural hazards such as storms.

(6) Easy maintenance and inexpensive construction.

As regards items (1) through (3) above, the following measures are available.

(1) Installation of two substations so as to make it possible to keep power supply from one substation when the other gets out of order.

(2) Installation of two transformers per substation with one as a standby.

(3) Minimization of such troubles as voltage unbalance and fluctuations by receiving power from MERALCO's 115 kV busbar which has a big fault level.

(4) Installation of auto transformers at an interval of not exceeding 10 km.

Installation of traction substations somewhere near MERALCO's Malinta, Northport and Malibay substations shown in Fig. 5-3 was put to comparison studies. The findings are as follows.

Northport is located near Manila Station and at the center of the railway loads, but is rejected because it is short from other substations, because it will have to feed over some 40 km if electrification covers up to Carmona in future, and also because the substation premises are narrow yet complicated. For this reason, Malinta and Malibay are recommended. In this case, the lowest normal voltage for the train operation diagram in 2000 is 22.5 kV, and the lowest emergency voltage when one substation is in failure is 20.8 kV or above 19 kV necessary for train operation. Thus, this arrangement is acceptable.

A sectioning post (SP) is required to be installed on the north of Tayuman "Y" in order to divide electric power between the two substations unless in case of emergency. This is because the power systems in the premises of Manila yard should at any rate be unified, the power systems for the South and the North Line should preferably be separated from each other.

It is also required to install subsectioning posts (SSP) for the purpose of minimizing operation troubles by localizing and rejecting faulty points.

The auto transformers should be installed for SS, SP, SSP and ATP at a spacing of not more than 10 km in order to provide against induction interference with telecommunication lines. Malinta and Malibay substations should each have 2 units of 15 MVA transformer, and each of the auto transformers should be rated at 2.5 MVA.

### 5-3-2 System of power supply from MERALCO to traction substations

What should be borne in mind in planning the traction substations is the fact that the 115 kV single-phase power received from MERALCO substations is to be stepped down to 55 kV through single-phase transformers. MERALCO is seriously concerned about the evil effects of single-phase power reception. But the following explanation made in reference to a comparison between single-phase and three-phase power reception will demonstrate that MERALCO is meeting trouble halfway. Table 5-2 shows a comparison between single-phase reception and three-phase reception.

Table 5-2 Single-phase reception vs. three-phase reception

| Item | Single-phase reception | Three-phase reception |
|---|---|---|
| Transmission line | Two wires alone are necessary if ground wire is counted out. Construction costs less than three-phase transmission line. | Three wires are required if ground wire is counted out. |
| Traction substation | Because of single-phase equipment, the construction cost is low, and maintenance is easy. | Because of three-phase equipment, the construction cost is high, and maintenance is complicated. (Transformer is required to be of the three-phase to two-phase conversion type like Scott-connected one.) |
| Voltage unbalance factor | Greater than in three-phase reception. So far as PNR is concerned, the voltage unbalance factor can be limited to within 1%, and there will be no problem. | Smaller than in single-phase reception. |
| Number of dead sections | Where a pair of traction substations are used, the number of dead sections is one. For the train operation, the smaller the number of dead sections, the better. | In the case of a pair of traction sub-stations, the number of dead sections is three. |

As is clear from the table, the single-phase reception is cheaper because single-phase transmission lines and single-phase equipment can be used to simplify the system arrangements. From the viewpoint of train operation, the single-phase reception scheme dispenses with a dead section at the substation when the three-phase scheme necessitates it as two-phase voltages stepped down are different in phase angle by 90°. Namely, the train operator is relieved of otherwise taking trouble to cut off the motor and coast clear of the dead section.

The voltage unbalance factor is defined as follows, and its tolerance limit is usually set at less than 3%.

In the case of single-phase transformer:-

$$K = \frac{P}{P_S} \times 100\ (\%)$$

In the case of T-connected transformer:-

$$K = \frac{P_A \sim P_B}{P_S} \times 100\ (\%)$$

Where, K: voltage unbalance factor, %

$P_S$: short circuit capacity at receiving point, kVA

$P_A, P_B$: 2-hr. mean load of teaser, kVA

P: 2-hr. mean load of single-phase transformer, kVA

According to MERALCO, Malinta and Malibay substations currently have a $P_S$ of about $1{,}926 \times 10^3$ kVA and $4{,}002 \times 10^3$ kVA, respectively. As discussed later, these substations are expected to have, in 1987, a one-hour maximum mean load under normal operating conditions of about 6,900 kVA and 9,200 kVA, respectively. (The two-hour mean load is a little smaller than the one-hour maximum mean load.) This means that these substations will have a voltage unbalance factor of respectively 0.36% and 0.23% in 1987. Even in a poor condition that one traction substation has to feed the entire railway load when the other is in failure, the voltage unbalance factor will remain as little as 0.84% for Malinta and less than 0.4% for Malibay, by far less than the limit 3%.

The single-phase reception system is a standard practice for AC railway electrification chiefly in Europe. In Japan, AC railway electrification was made when the electric supply system was not strong, and three-phase-to-two-phase transformers like Scott-connected ones are still used except for specific sections.

The on-off control of the circuit breakers and disconnecting switches located at SS, SP and SSP should be carried out from the control center to be installed at Manila Station.

### 5-3-3 Electric power necessary for railway electrification

Table 5-3 shows the power and energy required to be delivered by Malinta and Malibay substations in 1987 and 2000.

Table 5-3 Electric power and energy necessary for railway electrification

| Name of substation | Power (kW) | | Electric energy ($10^6$ kWh) | |
|---|---|---|---|---|
| | 1987 | 2000 | 1987 | 2000 |
| Malinta | 5,500 | 10,100 | 22 | 36 |
| Malibay | 7,400 | 13,000 | 46 | 76 |

### 5-3-4 Overhead contact wire facilities

The electric power from traction substations is supplied to the cars through overhead contact wire facilities consisting of contact wires, supporting structures, insulators, etc.

#### 1. Requisites to overhead contact wire facilities

The overhead contact wire facilities should satisfy the following requirements.

(1) to have an ample electrical strength to satisfactorily accommodate high-speed large-capacity moving loads.

(2) to be least susceptible to electrical faults, such as contact wire breakdown, and to be high in reliability.

(3) to cause little or no chattering between contact wire and pantograph.

(4) to have an ample mechanical strength to stand against temperature changes and such external forces as winds.

(5) to be easy in maintenance and low in maintenance cost.

(6) not to hamper the field of vision of the train.

## 2. System of overhead contact wire

At present, many kinds of overhead contact wire systems have been employed in the world. For PNR, the two systems illustrated in Fig. 5-8 are recommended.

o Main lines ..... Simple catenary suspension system

This system is suitable for high-speed transit service of not exceeding 100 km/hr., and is easy and inexpensive in maintenance and construction because of its simple structure.

o Lines within car depot ..... Direct suspension system

This system is suitable for low-speed operation of not exceeding 45 km/hr., and its construction cost is less because of its simple structure.

FIG. 5-8 CATENARY SYSTEM

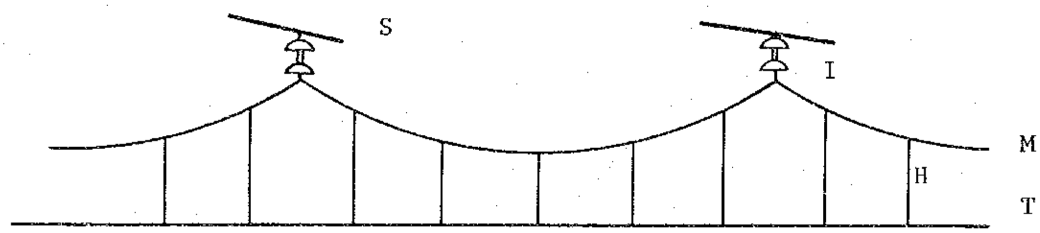



FIG. A SIMPLE CATENARY SUSPENSION SYSTEM

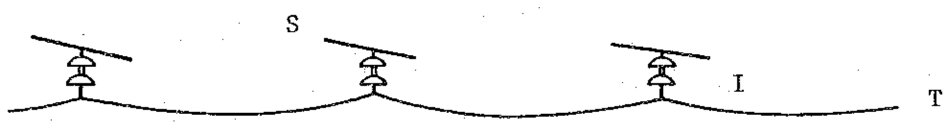



FIG. B DIRECT SUSPENSION SYSTEM

LEGEND

M: MESSENGER WIRE

T: CONTACT WIRE

H: HANGER

I: INSULATOR

S: SUPPORTING STRUCTURE

## 3. Arrangement of overhead contact wire facilities, and standard structure

The major components of overhead contact wire system and their standard structure are shown in Fig. 5-9 for two-track sections and Fig. 5-10 for the Manila-Tayuman "Y" four-track section.

The wires, their functions, materials and sizes are as follows, provided that the materials and sizes should be determined upon further studies and investigations.

AT feeder (AF)

This is a wire to feed electric power to the contact wire. Its maximum to-the-ground voltage is 27.5 kV. The voltage between the AT feeder and contact wire is 55 kV. The AT feeder is made of aluminum, and has a cross-sectional area of 95 $mm^2$.

Contact wire (T)

This is a wire for feeding electric power to the cars. The car takes in electric power by bringing its pantograph against the contact wire. The to-the-ground voltage of the contact wire is 27.5 kV. The contact wire is a copper conductor with a cross-sectional area of 110 $mm^2$.

Messenger wire (M)

This suspends the contact wire. It is made of steel and has a size of 90 $mm^2$.

Protective wire (PW)

This establishes a metallic circuit in the case of a ground fault as developed by a flashover fault of insulators for the purpose of ensuring ground fault detection by a relay. It is connected to the rail at an interval of several kilometers. The protective wire is made of ACSR and has a size of 40 $mm^2$.

Ground wire (GW)

The ground wire is installed for the purpose of protecting the contact wire system from lightning fault. It is made of steel and has a size of 55 $mm^2$.

Power distribution line for signal (H)

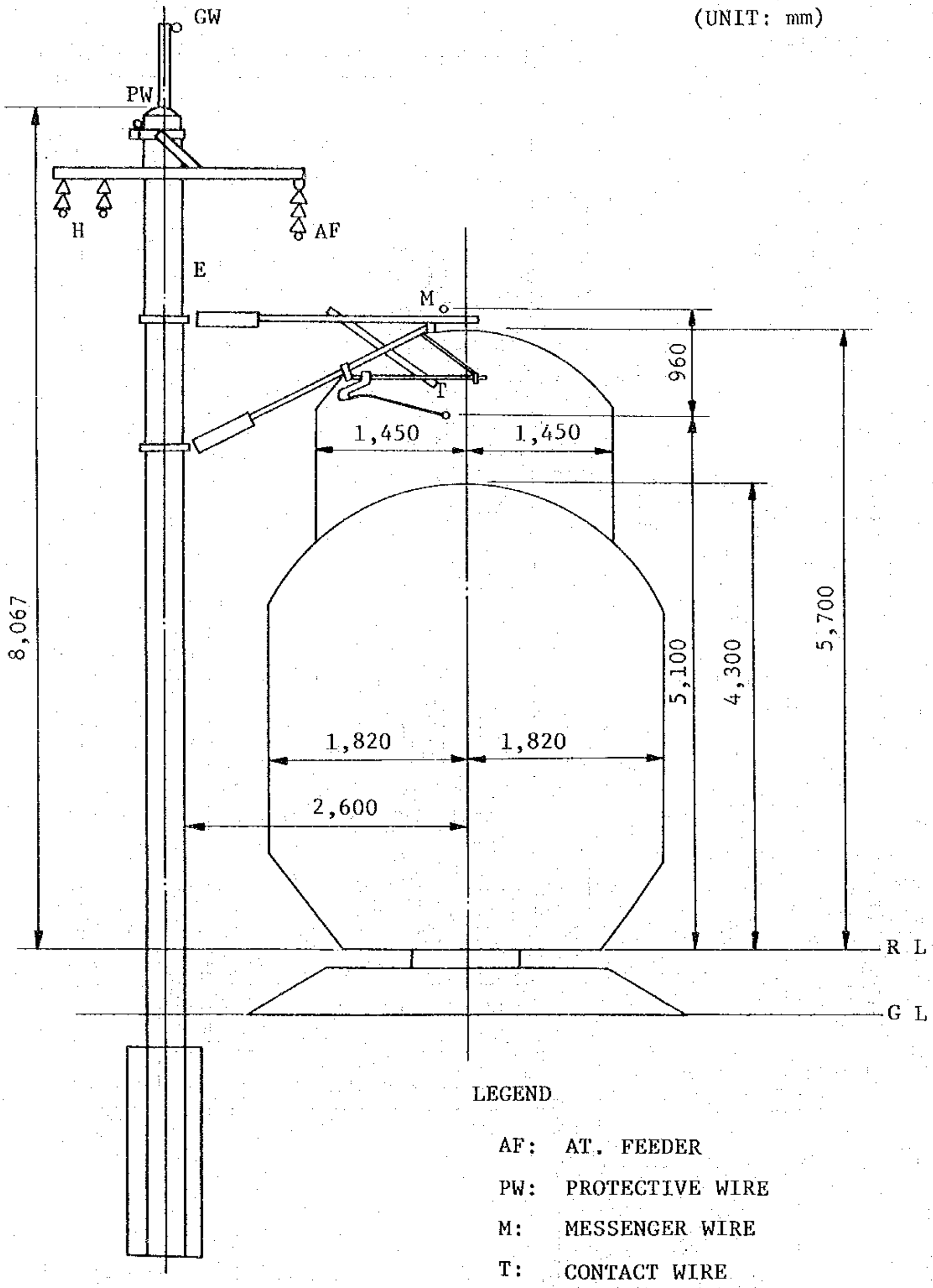
Where the power distribution line is not available, this line is installed for the power distribution line of signal.

The heights of contact wire and others shown in Figs. 5-9 and 5-10 are standard values. The contact wire and messenger wire may have a minimum height of 4,550 mm and 4,900 mm respectively depending on location. Accordingly, the overbridges of 5,000 mm high which are seen in Sta Mesa, Malinta, etc. do not affect the contact wire system at all.

Fig. 5-9 STANDARD STRUCTURE BETWEEN STATION

(AC A.T. SYSTEM)

(UNIT: mm)




LEGEND

AF: AT. FEEDER

PW: PROTECTIVE WIRE

M: MESSENGER WIRE

T: CONTACT WIRE

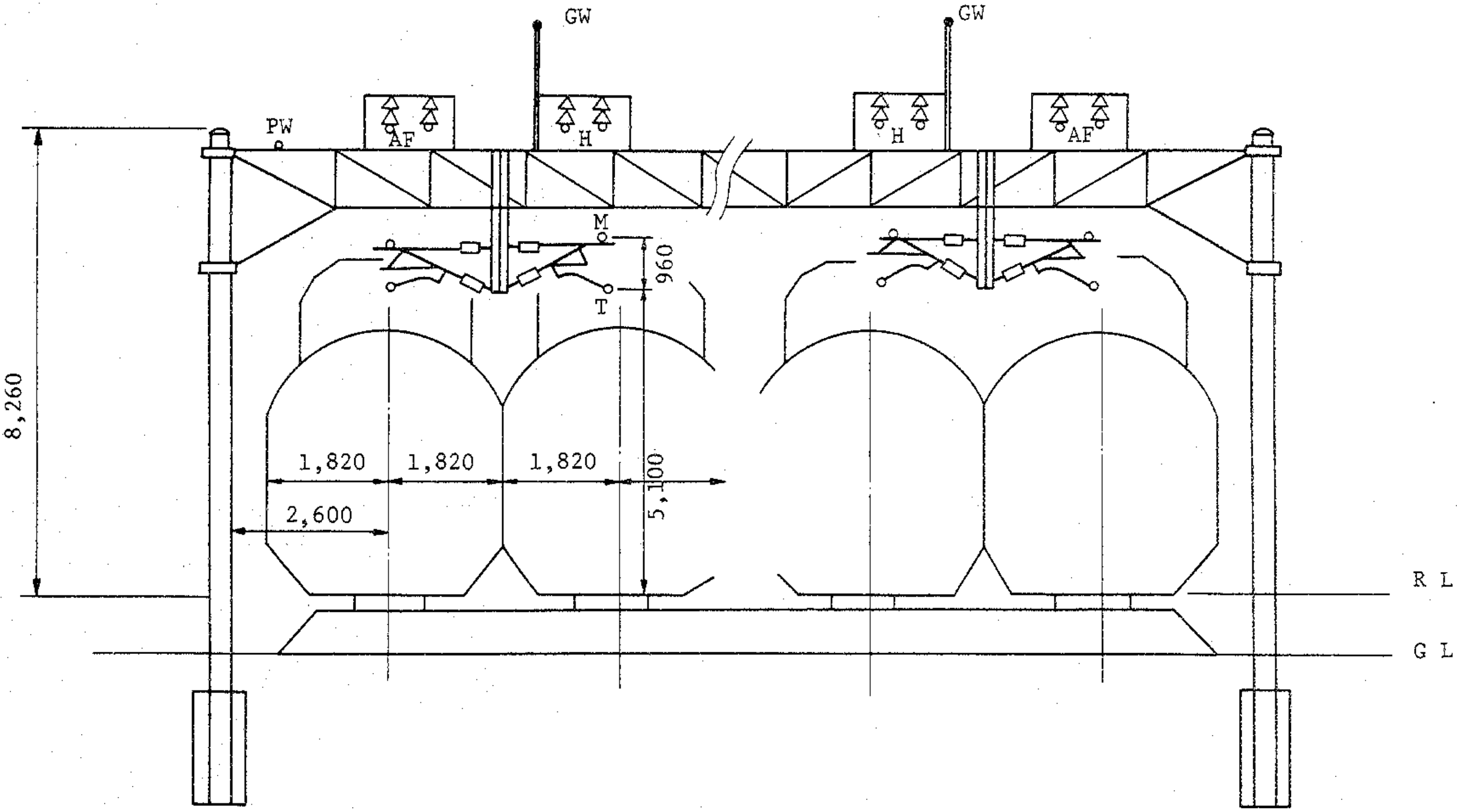
GW: GROUND WIRE

E: EARTH LEADING WIRE

H: POWER DISTRIBUTION LINE FOR SIGNAL

Fig. 5-10 STANDARD STRUCTURE IN 4 TRACKS SECTION BETWEEN STATION

(AC, AT SYSTEM) (UNIT: mm)



## 4. Supporting structures for the contact wire system

Concrete poles, steel poles and wooden poles are available as supporting structures of the contact wire system.
Except for specific parts of the four-track section, it is recommended to employ concrete poles. The concrete poles can serve almost permanently, dispense with maintenance because they are passivated against corrosion, and their costs of construction are less than steel poles'.
The beam for supporting the messenger wire and contact wire is available in the following types.

Steel fixed beam, Span catenary wire beam, Hinged cantilever beam (shown in standard structure)

The hinged cantilever beam has its fulcrum moving in the lengthwise direction of the contact wire to absorb the expansion and contraction of contact wire with temperature changes, and also facilitates maintenance work.
Thus, it is recommended to use this beam for ordinary sections and the fixed beam for station premises and the like where a good number of overhead wires are to be supported.

## 5. Tension adjust device

The catenary expands and contracts under the influence of ambient temperature changes, load changes and secular creep elongation. But for the purpose of ensuring good current collecting performance, the catenary tension must be kept, as far as possible, at a constant value. To this end, the wheel tension balancer is installed.

## 5-4 Master Plan for DC Railway Electrification

The voltage of the contact wire system used in the DC electrification of rapid mass transit railway is mostly either 1,500 V or 3,000 V. The 1,500 V system in which JNR and other major railway companies have much experience is studied for the electrification of PNR commuter service. Fig. 5-11 shows a feeding system, and Fig. 5-7 the location of traction substations.

### 5-4-1 Concepts of feeding system, and location of traction substations

What must be considered first in the planning of the feeding system and other facilities is just the same as with AC electrification. To put it more concretely, the following must be taken into account for the planning of the DC feeding system.

(1) The DC traction substation is far less in unit capacity than the AC one, is a three-phase load, and thus should be served from a 34.5 kV transmission system.

(2) The traction substation should be fed from the 34.5 kV bus line where MERALCO's substation is available or is served direct from the transmission line if not available.

(3) Adjacent DC traction substations should be run in parallel.

(4) Each DC traction substation should be provided with a filter for the purpose of preventing induction interference with the communication lines.

The location of the DC traction substations should be determined after due consideration of the following.

(1) The minimum allowable supply voltage to the cars is 900 V. The running speed of the cars is nearly proportional to the supply voltage, and the supply voltage should be kept more than 1,100 V so far as the punctuality is a must as on a commuter line. If one traction substation gets out of order, its adjacent substation should back up it. In this case, a minimum voltage of 900 V may be permitted exceptionally.

(2) The traction substations should be located near MERALCO's substations.

(3) The dead-end traction substation should be located at such a place that will permit oneway feeding.

(4) The dead-end traction substation should be installed with two units of silicon rectifier with one as a standby for the purpose of increasing its operating reliability. This engineering consideration is necessary because if the dead-end substation is plunged into a total failure, the section it has covered will no longer be assured of a normal voltage even with the extended feeding by the adjacent substation.

The considerations above lead to the installation of ten traction substations for the Malolos-Sucat section as illustrated in Fig. 5-7. For the electrification of the line from Sucat all the way to Carmona, it is only necessary to install an additional DC traction substation at San Pedro L.

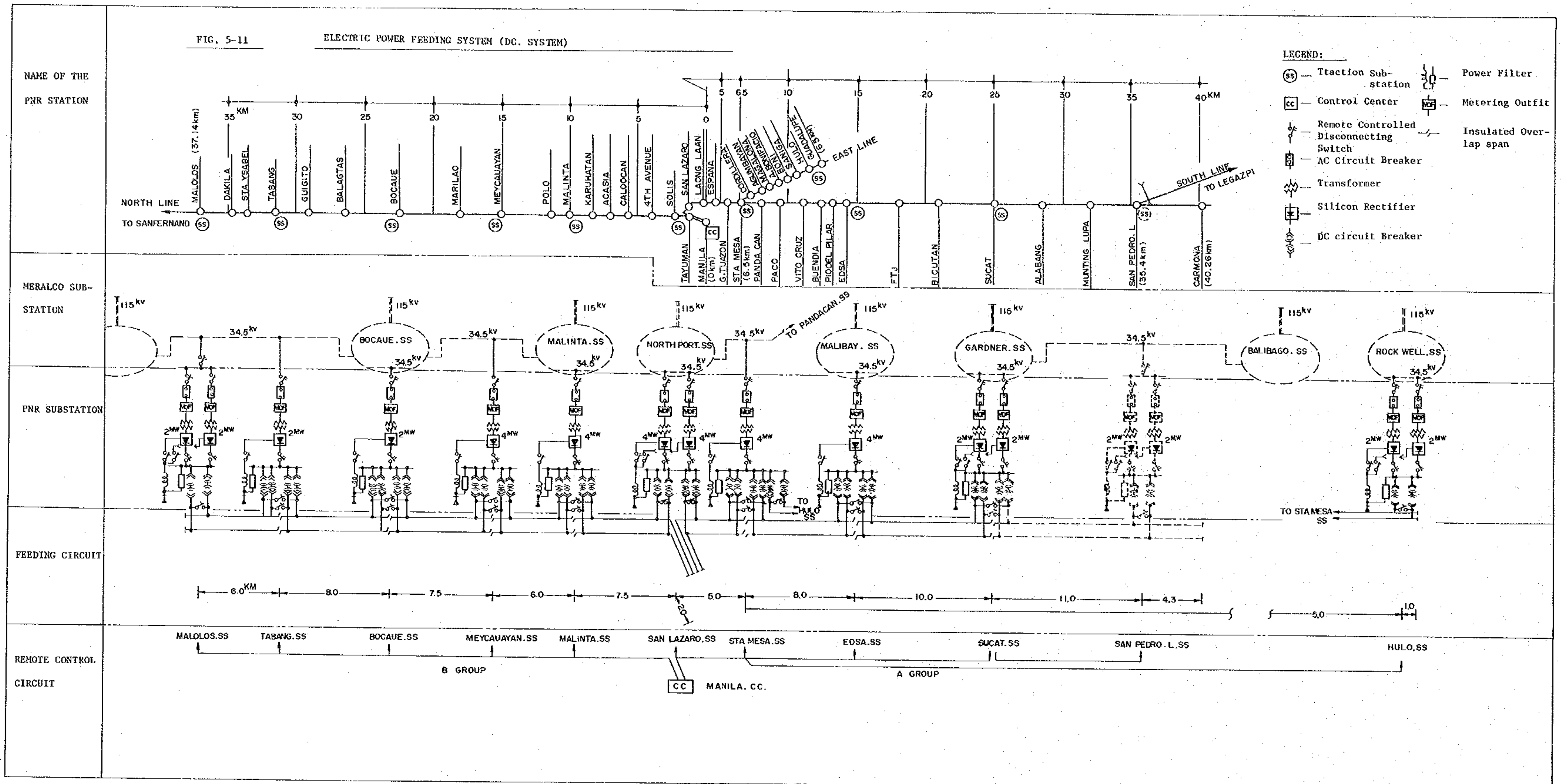
### 5-4-2 System of power reception of DC traction substations

The DC traction substation is smaller in unit capacity than the AC one, and is able to receive three-phase power. Namely, it does away with such a powerful line as 115 kV system indispensable for AC traction system. It can be served direct from the 34.5 kV system without developing voltage unbalance or fluctuation that may sacrifice the general consumers. The major equipment to be installed at the DC traction substation includes silicon rectifier, transformer, DC breaker, AC breaker, disconnecting switch, switchboard, control apparatus and so on.

The capacity of the silicon rectifier varies depending on substation. The larger substation will use a silicon rectifier set of 4 MW, while the smaller substation will be rated at 2 MW per set.

All these traction substations will be remote controlled from the control center to be located at Manila Station.

FIG. 5-11 ELECTRIC POWER FEEDING SYSTEM (DC. SYSTEM)



## 5-4-3 Contact wire system

Given here are the disparities of DC contact wire system from the AC counterpart.

The major components of which the contact wire system are composed and standard structure are illustrated in Fig. 5-12 for the two-track sections and in Fig. 5-13 for the four-track sections. The nomenclatures, functions, materials and sizes of wires are as follows.

Feeder (F)

This is a wire for feeding electric power to the contact wire. Its to-the-ground voltage is 1,500 V. It is made of two aluminum conductors of 510 $mm^2$.

Contact wire (T)

The contact wire is connected to the feeder at an interval of 250 m. It is made of copper, and has a size of 110 $mm^2$.

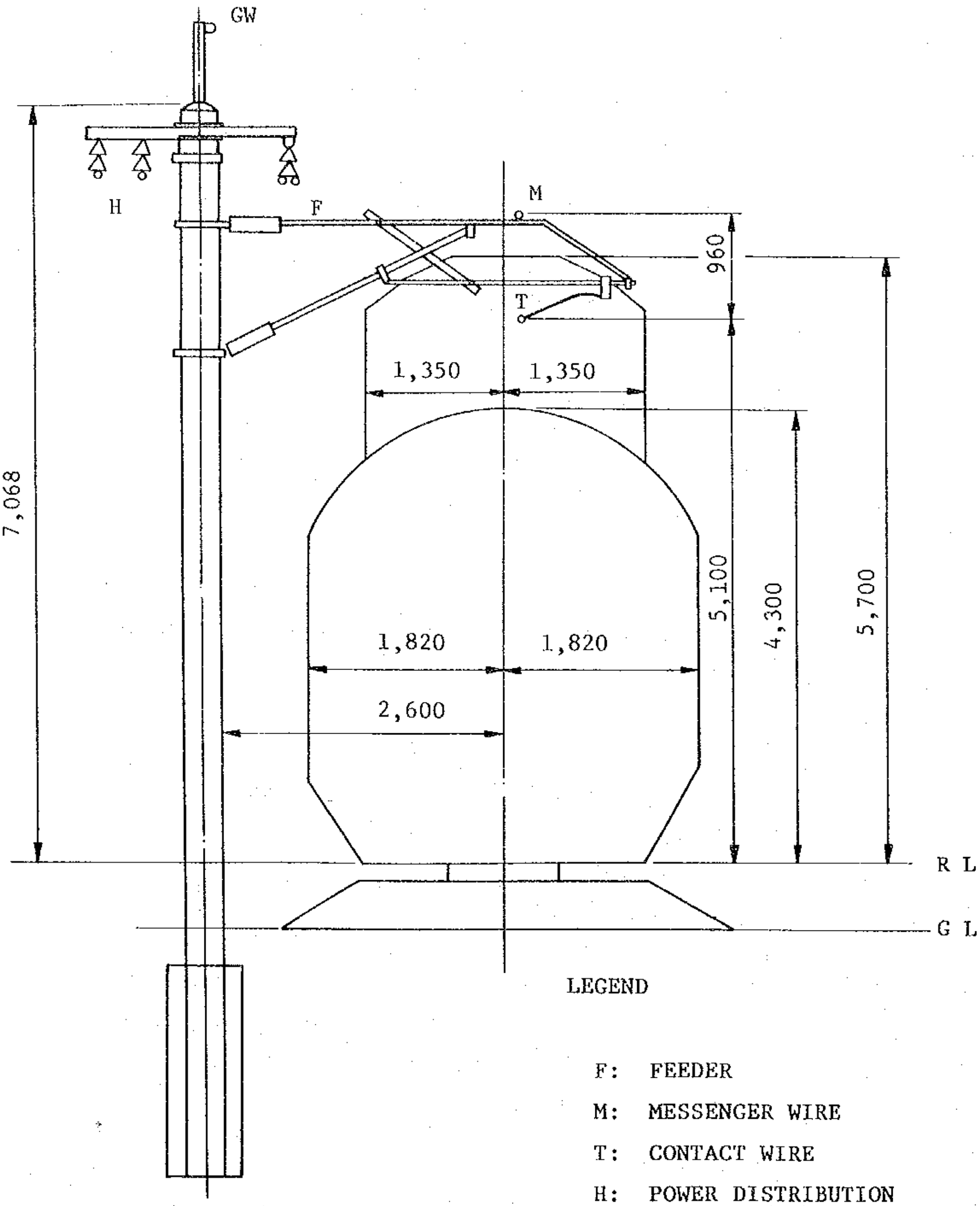
Messenger wire (M)

This wire suspends the contact wire, and is made of steel. Its size is 90 $mm^2$.

The heights of contact wire and others are just the same as with the AC system. The contact wire supporting structures and tension adjust device are also the same.

Fig. 5-12 STANDARD STRUCTURE BETWEN STATION
(D. C. SYSTEM)

(UNIT: mm)




LEGEND

F: FEEDER

M: MESSENGER WIRE

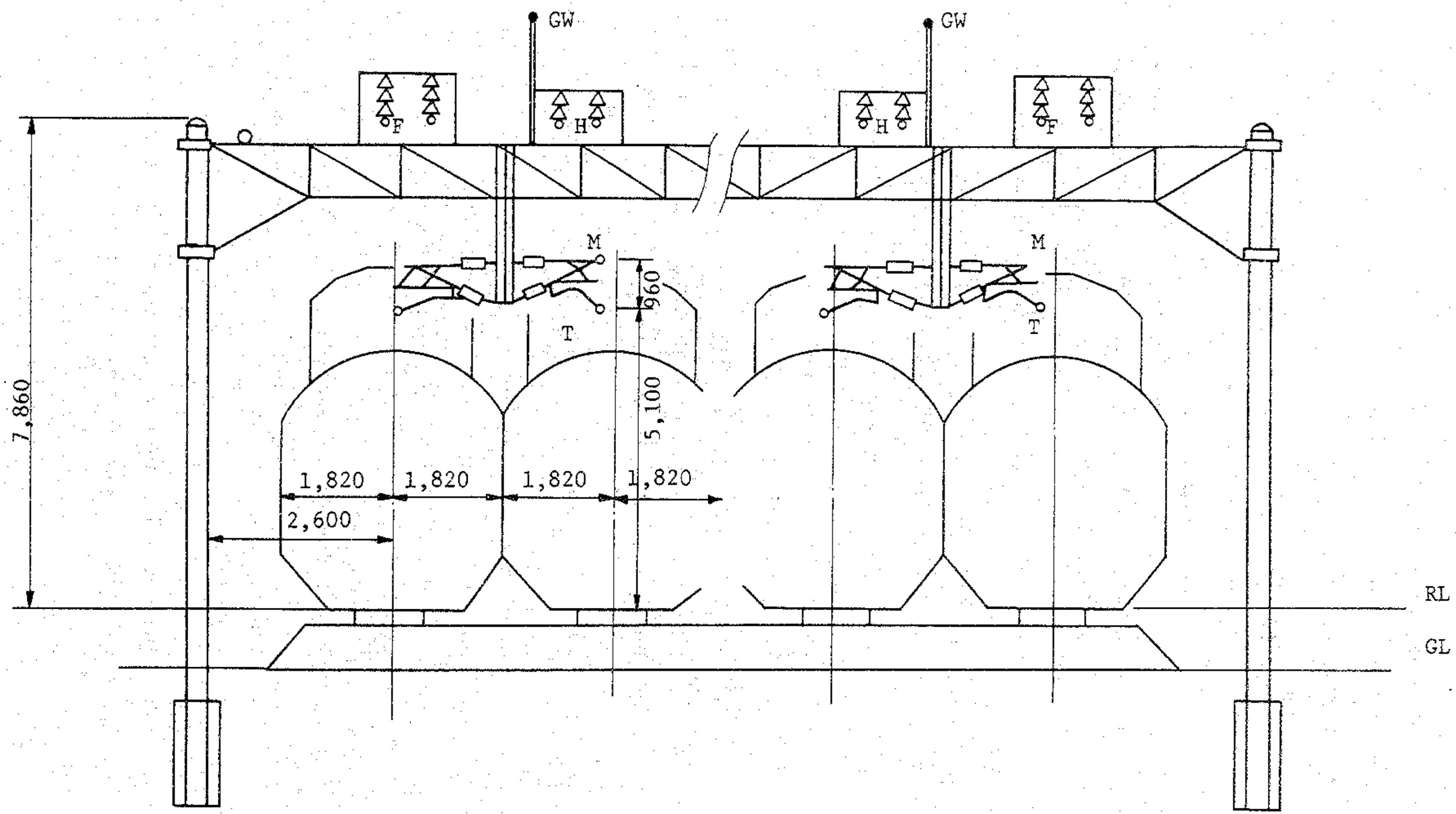
T: CONTACT WIRE

H: POWER DISTRIBUTION LINE FOR SIGNAL

GW: GROUND WIRE

Fig. 5-13 STANDARD STRUCTURE IN 4 TRACKS SECTION BETWEEN STATION

(D.C.SYSTEM) (UNIT: mm)



## 6. Rough Estimate of Construction Costs

### 6-1 Presuppositions

1. The costs for electrification work are to be calculated for each section (Manila-Sucat; Sta Mesa-Guadarupe; Manila-Meycauayan; Meycauayan-Malolos).

2. The construction costs are to be calculated for both AC and DC electrification.

3. The construction costs to be calculated are as follows.

   o Costs of ground facilities for electrification (substations, overhead contact wire system, etc.)

   o Costs for improvement of signalling and telecommunication facilities

   o Rolling stock costs

4. The materials and supplies available in the Philippines will be made the best use of, provided that the electrical machines and appliances will be imported.

5. All the construction work will be undertaken by local labor.

6. The prices of imports are in terms of CIF, Manila Port, and do not include the charges for unloading, warehousing, transport and cargo handling, provided that the prices for rolling stock are in terms of FOB, Japan.

7. Import duties are excluded.

8. The costs for substation lots and rights-of-way are not included.

9. The costs for improving the existing signal facilities between Caloocan-Bictan section are included.

10. In the case of AC electrification, the costs for cabling the unshielded overhead telecommunication lines along the railways are included.

11. The escalation of commodity prices in future is not taken into account.

12. The exchange rates are set as follows.

    1 US$ = 7.25 ₱, 1 ₱ = 33 ¥

## 6-2 Construction Costs

The costs of ground facilities for electrification calculated according to the conditions set forth in para. 6-1 are as listed in Table 6-1.

The costs of ground facilities necessary for electrification between the Malolos-Sucat section are estimated to amount to about $126 \times 10^6$ ₱ (of which about $105 \times 10^6$ ₱ by foreign currency) for the AC scheme and about $139 \times 10^6$ ₱ (of which about $112 \times 10^6$ ₱ by foreign currency) for the DC scheme, showing that the AC electrification costs a little less than the DC electrification.

For the DC electrification of the Manila-Sucat section (Step 1), some $60 \times 10^6$ ₱ will be required.

## 6-3 Costs for Rolling Stock

Assuming that the number of cars required in 2000 is 300, the costs for them will amount to about $830 \times 10^6$ ₱ for AC electrification and $760 \times 10^6$ ₱ for DC electrification.

Table 6-1 Rough estimate of electification work

(in $10^3$ ₱)

| Section / Work | AC electrification (AT system) | | | | | DC electrification | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manila ~ Sucat | Sta Mesa ~ Guada-lupe | Manila ~ Meycau-ayan | Mey-cauayan ~ Malolos | Total | Manila ~ Sucat | Sta Mesa ~ Guada-lupe | Manila ~ Meycau-ayan | Mey-cauayan ~ Malolos | Total |
| Substation | 24,200 | 3,600 | 21,300 | 7,600 | 56,700 | 29,200 | 7,500 | 13,100 | 19,500 | 69,300 |
| Contact wire system | 23,500 | 4,600 | 11,400 | 17,900 | 57,400 | 26,700 | 5,300 | 12,900 | 20,400 | 65,300 |
| Signalling | 5,200 | 0 | 600 | 0 | 5,800 | 4,200 | 0 | 500 | 0 | 4,700 |
| Communications | 1,900 | 500 | 1,300 | 1,900 | 5,600 | 0 | 0 | 0 | 0 | 0 |
| Total | 54,800 | 8,700 | 34,600 | 27,400 | 125,500 | 60,100 | 12,800 | 26,500 | 39,900 | 139,300 |

Note: The foreign currey portion in the estimate above is as follows.

AC electrification ....... 105,100 ($10^3$₱)

DC electrification ....... 112,300 ($10^3$₱)

## 7. Investigations and Studies to be made before Electrification

The problems PNR is now facing are the easing of traffic congestion in Metro Manila and the improvement in transport services required in the immediate future.

PNR should therefore improve the existing track facilities and operating plans for increasing the transport capacity. The electrification is only a part of the processes to realize the reinforcement of transport capacity in an economical manner, and the following programs should be pushed forward concurrently.

1. Double-tracking work.
2. Improvement of car depot, storage tracks and station facilities.
3. Extension of platforms.
4. Grade separation.
5. Repair and upgrading of tracks.
6. Improvement of bridges and other elevated structures.
7. Improvement of signalling and communication facilities.
8. Modernization of track maintenance work.
9. Technical education and training.

To promote these problems, the following studies and investigations will be conducted from the technical point of view.

(1) Studies and investigations about the double-tracking facilities and station facilities for increasing commuter train services on the North and East Lines, procedure for double-tracking and station improvement, etc.

(2) Traffic engineer-assisted studies and investigations about the grade separation work necessary for increasing commuter train services.

(3) In-depth technical studies and investigations about the improvement of Manils Station facilities for the purpose of increasing commuter train services, along with cargo transport plans.

(4) Studies and investigations about the maintenance strategies and maintenance depot setup for commuter trains.

(5) In-depth technical studies and investigations about the track and rolling stock maintenance standards and the tooling for periodic track maintenance work for the purpose of preventing derailment troubles in the commuting sections.

(6) Technical education and training for the purpose of enhancing the state of art in the maintenance of tracks and electrical facilities.

In additiona, the following should also be studied for improving the transport services.

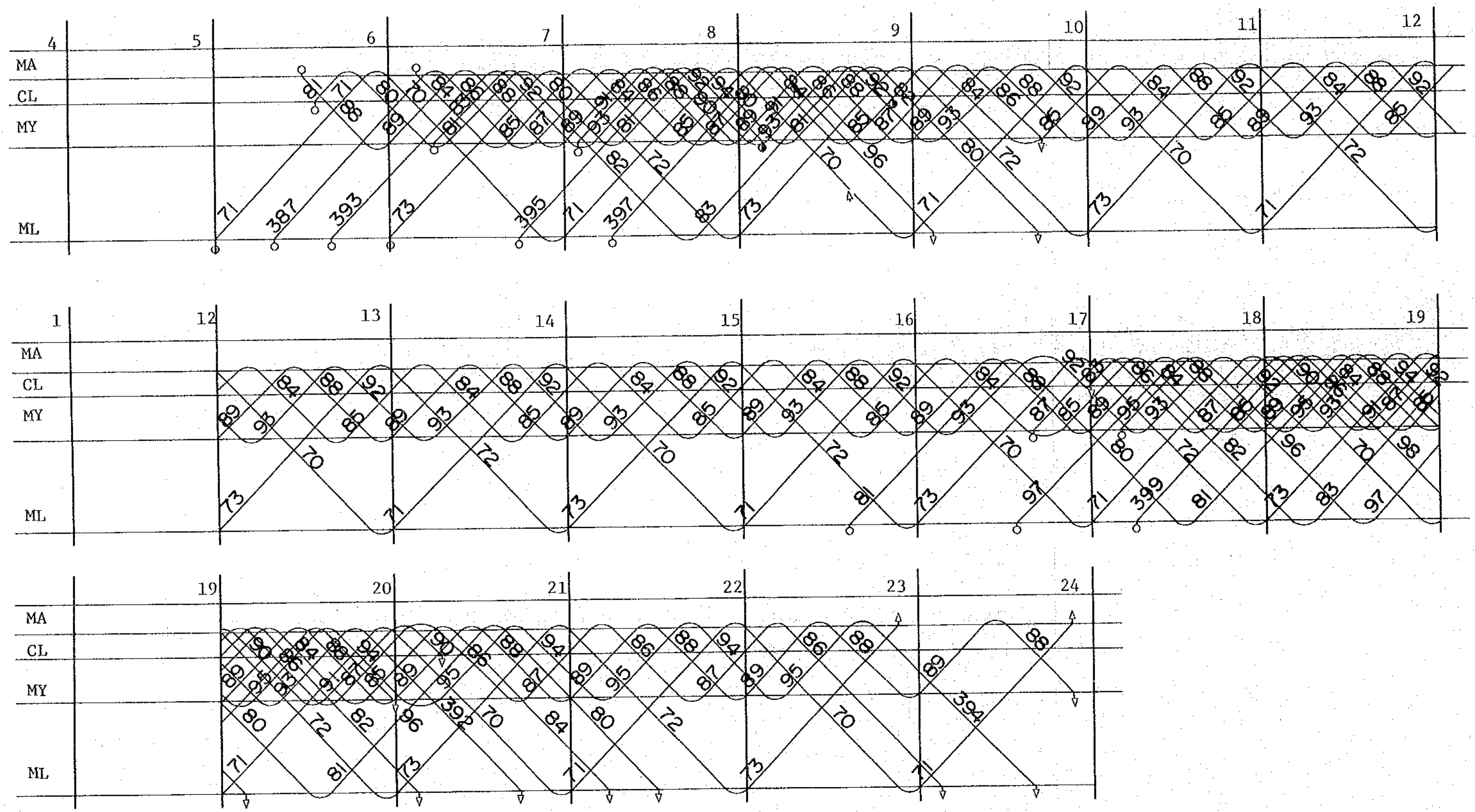
(1) Efficient ticket vending system and barrier system.

At present, ticket clipping and collection is carried out manually, and should be replaced with an efficient system with increase in the number of passengers.

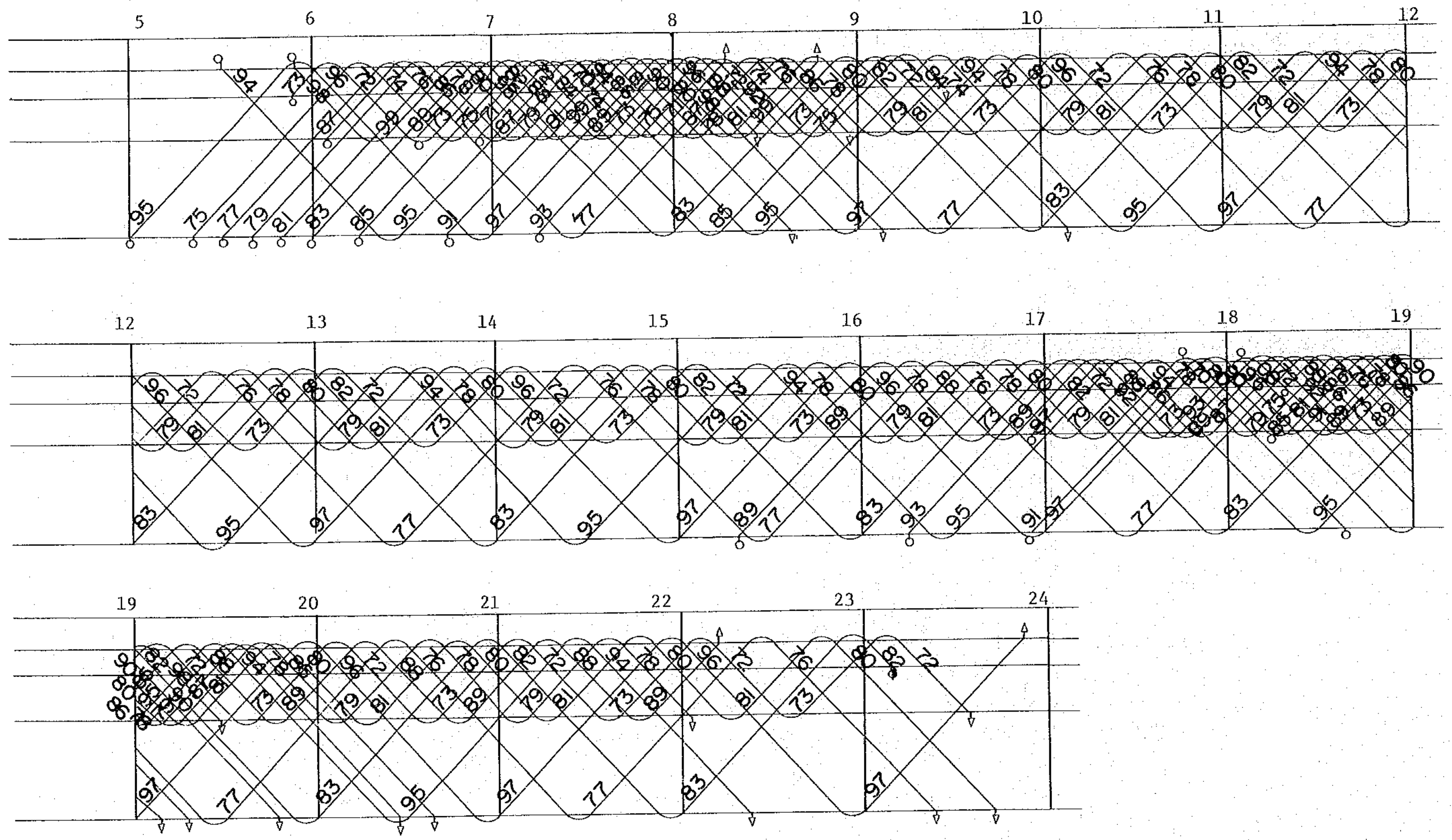
(2) Improved information service.

At present, the passengers are informed of train services by announcement and time table. The directional signs, markings and other types of information about train services to be carried by trains or installed on the platforms should be improved.

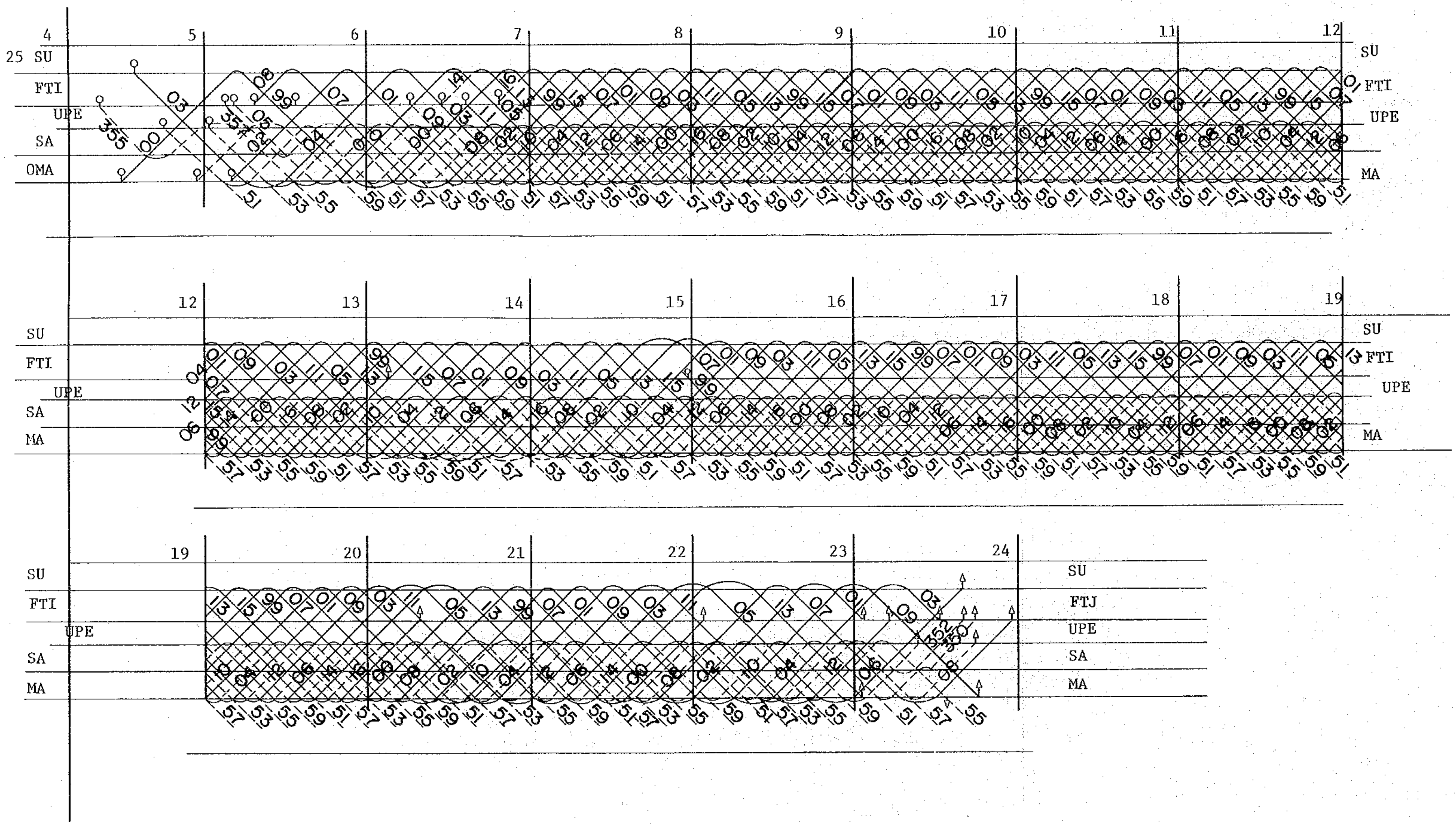
Tentative train operating diagram of north line (1987)



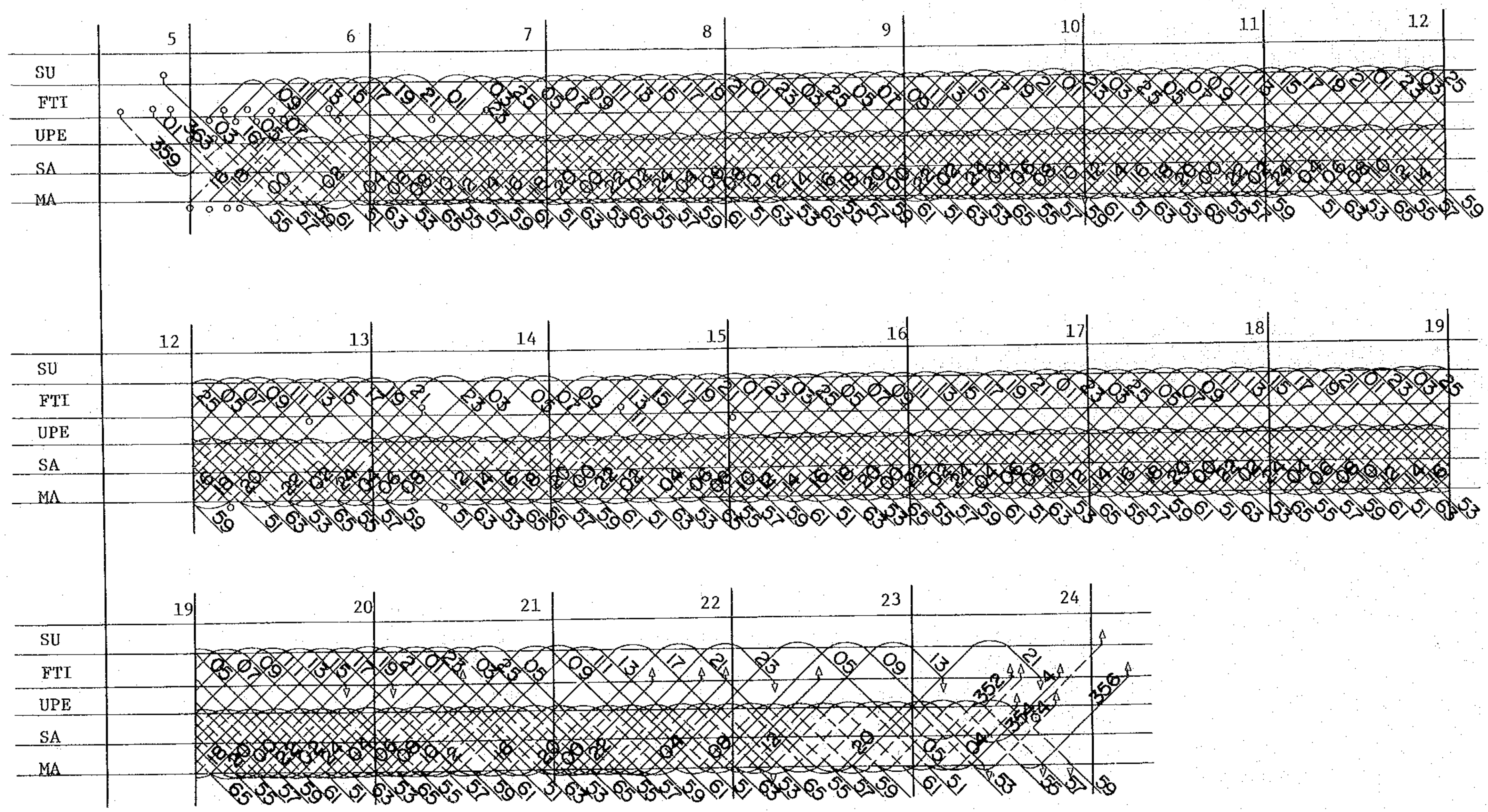
Tentative train operating diagram on north line (2000)



Tentative train operating diagram of south line (1987)



Tentative train operating diagram of south line (2000)



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