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## **Seminar 5**

**Urban Transport Structures**

**Structures dans les transports urbains**

**Bauwerke für städtische Transportsysteme**

Organizer: John Breen,

USA

Chairman: S.P. Chakrabarti

India

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## Second Stage Expressway System in Bangkok

Deuxième phase du système de voies express à Bangkok

Zweite Ausbaustufe von Bangkoks Expressstrassennetz

### **Ekasit LIMSUWAN**

Prof. in Struct. Eng  
Chulalongkorn Univ.  
Bangkok, Thailand



Ekasit Limsuwat, born 1947 in Bangkok, received his Civil Engineering degree from Chulalongkorn University. He obtained his Ph.D. from the University of Texas at Austin, worked for Centre for Highway Research in the USA. In Bangkok he worked with several Consulting firms in structural concrete, bridge and building structures.

### **Theerapong ATTAJARUSIT**

Deputy Governor  
Expressway & Rapid Transit Authority  
Bangkok, Thailand



Theerapong Attajarusit, born 1942 graduated from H Chulalongkorn University and completed his post-graduate study from Univ. of Illinois at Urbana the USA. He has been teaching at Khonken University for several years, worked with Consulting firm in Bangkok and joined ETA as a director of the Technical department. He has been Deputy Governor for planning and development since 1991.

### **SUMMARY**

Second Stage Expressway System in Bangkok (SES) is one of the most outstanding projects in the urban transportation system. The project has studied and planned, for more than two decades, the master plan has been implemented for the first stage and now for the second stage, while the third and fourth stages are in the process of design and study, respectively. Project development of the SES in cooperation with the management to privatization at a great success will be introduced. Project execution has carefully been pursued to obtain the most reliable project of effective productivity, high quality and accurate performance. The structural systems of segmental box girder and U-beam section will be presented with their appropriate construction techniques. The operation system for the SES will also be discussed concerning toll collection, revenue, traffic regulation, inspection, repair and maintenance.

### **RÉSUMÉ**

La deuxième phase du système de voies express à Bangkok (SES) est l'un des plus remarquables projets dans le domaine des transports urbains. Cette réalisation a été étudiée et planifiée durant plus de deux décennies; elle comporte le projet principal ayant déjà été exécuté au cours de la première étape, puis la seconde étape actuelle, enfin les troisième et quatrième phases qui sont en cours d'étude. L'article présente le développement du projet de la deuxième phase du SES avec le concours d'une gestion privatisée de grande ampleur. L'exécution de ce projet a été poursuivie avec soin, en vue d'obtenir un ouvrage à fiabilité maximale, de haute qualité et offrant les performances ciblées. En outre, cet article expose les systèmes structuraux comportant les poutres-caissons en segments et les poutres à section en U, ainsi que les techniques de construction adéquates. Il analyse l'ensemble opérationnel du système de voie express SES, quant à la perception des droits de péage, la régulation du trafic, les inspections de contrôle, les réparations et l'entretien.

### **ZUSAMMENFASSUNG**

Der Ausbau von Bangkoks Expressstrassennetz ist ein sehr ambitioniertes Vorhaben, dessen Projektierung bereits über zwei Jahrzehnte währt. Zur Zeit wird die zweite Stufe des Masterplans umgesetzt, die dritte und vierte sind in Projektierung bzw. Studienphase. Mit grossem Erfolg wird die Privatisierung des Projekts vorangetrieben, wobei Landerwerb, Vergabe, Managementauswahl und Finanzierung besonderen Anforderungen hinsichtlich Effizienz, Qualität und Zielerfüllung unterlagen. Als Tragsystem wurden segmentierte Hohlkästen und U-Querschnitte gewählt. Der Beitrag bespricht auch das Betriebssystem hinsichtlich Strassenbenützungsgebühr und Amortisation, Verkehrsregelung, Inspektion und Unterhaltung.



## 1. INTRODUCTION

Bangkok is a wellknown beautiful city in the East, it is named as Vanice of Asia since water transportation had been used for long period in the past. But now Bangkok becomes a big city of the most serious traffic congestion. Bangkok has developed to so much in the last two decade, canels had been converted to road ways or drainage system instead of serving transportation system as usual. The population in Bangkok now is about 5 million in the metropolis or 8 million in the Greater Bangkok Area (GBA) including surrounding suburban. The population as expected to grow and may become 10 million within a decade.

Traffic congestion in the metropolis are very serious and become one of the nation critical problem. Vehicle speed on various main road are lower than 10 kilometer per hour in the rush hour and the people are suffered from travelling times in the city. The major cause may consider from poor town planning, too many vehicle on the road, and lack of efficient public transportation.

In solving the traffic problem, various means have been introduced such as expressway system, mass transit system, elevated highway, improvement of train services, and implement of water transportation. The Second Stage Expressway System (SES) is a continuation project of the First Stage Expressway System (FES) with an approximate 40 kilometer has been established and implemented to link with the FES at Makhasan, central interchange. Total cost of the project will be Baht 27.5 billion (US \$ 1.10 million) within 5 years of construction. The first phase of 27 kilometers is supposed to open for traffic in March 1992.

This paper will present development of the project, project execution, operation and maintenance of the whole system. The Structural system for the expressway, and construction techniques will also be introduced as the most effective planning and scheduling to accommodate the execution period of 6 years including land acquisition, design, and construction.

## 2. PROJECT DEVELOPMENT

The study on long term improvement of Bangkok transportation system had been conducted between 1971-1975 by expert team arranged under bilateral assistance from Republic of Germany. In accordance with such report, the Expressway and Mass Transit Authority (ETA) has been established since 1972 to responsible for implementation the long term project. The First Stage Expressway System (FES) had started by then and opened for operation since 1982. of first phase and followed by the success of a longest single plane cable stayed bridge in 1987 of the second phase. The Master plan of multi-projects for solving traffic congestion in Grater Bangkok have been summeried in Fig 1 including rapid transit project, and expressway systems; stage 1, 2 and 3, respectively.

The Second Stage Expressway System (SES) had been jointly studied by Japanese International Cooperation Agency (JICA) and ETA to recommend the route as shown in Fig 2, consists of two routes North-South from Chang Wattana to Bangklo (25 km) and East West route from Makkasan to Srinakarin Road (13.5 km). In detail design, East route of 2 km along San Saeb Canal had been included for purpose of combining and dispurising the traffic.

The development of SES will improve the traffic congestion in the Greater Bangkok Area (GBA), especially in the central Bangkok Metropolis as a result of a network formed between the SES and the FES. The new expressway to the North and East will help ease the traffic density in the city center. Travel time can be saved by 20% of normal travelling period and travelling speed can be increased by 24% so it will result in the reduction of traffic expense by Baht 14.0 million (US\$ 0.70 million) per day. The SES will encourage commercial and residential development along its route. This will have the additinal benefit of spreading economic development through-out the Greater Bangkok Area. Better roads and reduce traffic congestion has improved psychologically effect on motorist which can not be measured in term of money.

The feasibility study of the SES was also considered by the office of the National Environment Board and the subcommittee controlling and co-ordinating the project relating to the surveys, designs and studies of the environmental impact. The subcommittee are considered representatives of various concerned offices.

### 3. PROJECT PRIVATIZATION

The cabinet passed a resolution for the ETA to consider a private investment in the SES project by mean of the grant a concession to the private sector to build and manage the project in accordance with conditions and procedures prescribed by the ETA.

The project privatization is a joint success between the government and the private sector for the development of the country. The investment value of the SES makes it the world's second largest public utilities concession project. This project is aimed at the spread and coordination of profit, rather than at a party's benefit or loss. The Bangkok Expressway Company Limited (BECL) has been awarded in this SES project with the term and conditions of the concessions as follows:

The investor must have a registered capital of approximately 20 percent of the project value which must not be less than Baht 1,800 Million Baht (US.\$ 702 million).

BECL will bear the total costs of the construction and accessories and the investment risks without the government's guarantee to any loans.

The expressway must be constructed according to the required standards of the ETA and the construction must commence by 1990 and be completed by 1995 in respect of the first stage covering 39 kilometers.

BECL will refund the cost of land acquisition arrangement with interest at total of Baht 16,815 million (US.\$ 673 million) in the last 15 years.

The toll rate for the urban and the suburban area must be Bath 30 (US.\$1.20) and Bath 15 (US.\$0.60), respectively with the discount of Bath 5 (US.\$0.20) for the use of a combined area. The rates must be adjusted in accordance with the inflation rate at every 5 year

The toll revenue collected in the urban area will be shared between the ETA and BECL at the rate of 40/60, 50/50 and 60/40 in respect of the first, second, and third nine year periods, respectively.

The Expressway system and its accessories will belong to the ETA after the expiration of the 30 year period.

### 4. PROJECT EXECUTION

ETA put all of its effort to achieve the success of projects under its responsibility. The increasing number of the FES users has shown the demand and favor of using the expressway. Besides ETA successfully invited private sectors to invest in the SES and the Mass Transit System, of which a huge sum of investment is needed, so the implementation of project on privatization basis has lessened the financial burden of the government. In addition, ETA has also implement the Third Stage and the Fourth Stage Expressway System Project and the Ekamai-Ramindra Project to cope with the ever increasing traffic volume.

The Bangkok Expressway Co.,Ltd. (BECL) as awarded by the government, through the ETA for a 30 year contract to build and operate the SES has proposed the management team as shown in Fig. 3; comprising project manager, contractors under the supervision of ETA'S engineers; independent design checker and independent certification engineer. The construction of the 39 kilometers expressway is scheduled to commence on the March 1, 1990 (Fig. 4), with an estimated amount of investment of Bath 25,000 million (US.\$ 1,000 million)

The financial package of the SES project is recognized as an outstanding example of innovation and co-operation between local and foreign financial institutions. Shareholder of BECL authorized an increase in capital up to Bath 5,500 million (US \$ 220 million) with an initial capital as already been registered. Onshore credit facilities with a syndicate of 11 major local banks are structured to provide loan, guarantee, note, aval and acceptance financing of up to Baht 22,000 million (US \$ 880 million). The on-shore credit facilities are



further supported by an off-shore credit facility which was executed between 30 major international banks to provide guarantees to barrowings of an amount up to the lower of US.\$ 275 million.

Land acquisition to construct the SES has been carried out by ETA. The land and the building to be expropriated for the construction at total of 5,567 plots of land and 8,476 buildings. The Royal Decree issued in 1987 has been enforced so that ETA can gradually commence to appropriate the immovable property located in the right of way. A committee responsible for the initial price of immovable property, will consider the compensation under the criteria as

Land based on the higher appraised value will be in accordance with the cost of land as listed on the dated of enforcement of the Royal Decree

Building indemnity payment for buildings consists of removing cost, labor cost for reconstruction, design fee, and other compensation costs.

## 5. STRUCTURAL SYSTEM

The structural design of the SES uses the latest internationally proven technology and is intended to facilitate construction work with the minimum of disruption to traffic flow and the surrounding areas. A combination of segmental box and U-beam construction will be used. Both methods employ precast concrete components to create road deck, allowing precise quality control and as the components are cast off site, this again helps to minimize disruption to the traffic.

### 5.1 Substructures

Since soil condition in various parts of Bangkok are somehow difference from one places to the others, and due to soft soil condition then long piles of various length are used in this project. The average length of 40.00 meters are constructed by bored piles technique, except the location of pilecaps on swamp are where precast driven piles are used instead. Pile-caps are cast on pile groups with a typical of 5 piles per pier. The piers are box section with an average height of 10.00 meters and the caps are designed to accommodate the differential settlement of 50 mm. Structural portions of ramps or transition zones between ground and elevated section, the structures are designed and constructed by precast piles of different lengths, flat plate mate, retaining structures and back-fill to support the pavement. The structures will accommodate long term differential settlement and will obtain smooth ride.

### 5.2 Segmental Box

A single box girder is designed to accommodate 3 lanes traffic. The system consist of 14 segments per span, are assembled span by span and then stressing by dry joint external post-tensioned system as shown in Fig 5. Reinforced concrete continuous deck will joint each span together with special details to obtain smooth connection as which the expansion joint will be provided at every four spans. Fix and slide bearing units are used for each span to accommodate differential settlement, thermal elongation, creep, shrinkage and prestressing losses.

### 5.3 U-Beam

Only some section of the project that required multi-box girder due to some limitation of site congestion and pier location. The cross section as shown in Fig. 6 will be precast member of a U-shape. Top deck is cast in-situ to complete the whole section with provision of shear connectors at the interface between web of U-beam and the top deck. Ends of each span will link together as a diaphragm action for lateral stability and as for a continuous deck between span to obtain smooth connection. The span length of U-beam varies from 22.00 meter to 35.00 meter depends on the geometric configuration and pier location. The expansion joint will also be provided at every 4-6 consecutive spans in the same manner as the segmental box.

## 6. CONSTRUCTION

The SES currently under construction carried out by the Bangkok Expressway Company limited (BECL). The BECL in turn appointed Kumagai Gumi Company Limited as a Project Manager and five construction companies group have been awarded the six civil works contracts for the first phase. These include contracts for the substructure work at ground level, including construction of the main supporting columns for the elevated roadway and for the superstructure work, to erect and finish the road deck. The construction of the first phase currently underway includes the North-South route from Changwatana to Phayathai and the East-West route from Phayathai to Rama IX. It is due to be completed and fully operational during 1993. The second phase which is in the process of land acquisition will see the start of construction in 1992. It comprises 12 kilometer North-South connection between Phayathai to Bangklo at the Cable Stayed Bridge and East-West from Urupong to Rachadamri. This will be completed in 1995.

The construction techniques for segmental decks with total length of 20 kilometers, the box girder segments have been prefabricated at the world largest precast yard in Bang Pa-in, 60 kilometer away from Bangkok, are loaded onto the several vehicles of the groups fleet to deliver at the construction site where piers are ready for erection. Luanching gantries with total length of 96 meter are used to support and erect the segments prior to post-tensioning of external prestressing. Bearing units as elastomeric pad are installed after stressing and then top decks are simultaneously cast to meet the requirement as well as the parapet.

The construction of the expressway on North-South route along water supply canal, with some difficulties including narrow work spaces, time restriction, heavy traffic and noise problem with neighbourhood, then U-beam construction are used for this portion. The U-beams of average span length 30.00 meter and weight of 80 ton are cast in the precast yard at distance about 4 kilometers from the site, they are carried on a special transporter, to the site and then are hoisted from the transporter using 58 meters launching gantry which following the completion of each span as self-driven to the next section. Once U-beam installation is completed, reinforced concrete slab which make up the actual road deck are cast over precast formwork. The parapet wall then are constructed utilising travelling formwork systems to complete the whole roadway section.

## 7. OPERATION AND MAINTENANCE

The FES and SES will be operated adopting the flat tariff and on-ramp toll collection system. The location of the on and off ramp have been determined as shown in Fig 7. Toll gate structures, refuge island, toll booths, toll buildings and equipment installation are included in the cost.

Expressway lighting and other electrical system will be provided on throughway, interchange, rampways, at grade intersection, toll plaza, and toll buildings. Subsystem such as closed circuit TV system, sign, control system and emergency power unit will be installed and operated in the regular basis.

The operation system will be controlled by the ETA under the management of the BECL. For the structures and operating equipments will be subjected to general inspection on routine basis, daily, monthly or annually. According to this inspection, conditions of structures are evaluated and classified for the maintenance. Some items may be subjected to a detailed or special inspection and then repair or retrofitting may required as necessity. The ETA is forming a specific program to solve some problems of the traffic at the interface between the expressway system and the local roads of GBA, so that the stable transit system in the SES and traffic congestion will be relieved.



## 8. CONCLUSION

The Second Stage Expressway System in Bangkok has been well studied, planned and developed considering various aspects such as traffic volume, travel time, financial effects, social factor and environment impact. The concept of project privatization in co-operative between the government and private sector to reduce burden of investment, minimize construction duration and obtain excellent management. The structural system related to the construction techniques as employed in this project has proved to most the efficient and advanced technology to achieve high quality structures of better performance and to satisfy the project objectives in reduce traffic congestion in Bangkok at remarkable saves on travelling times and reduction of traffic expense.

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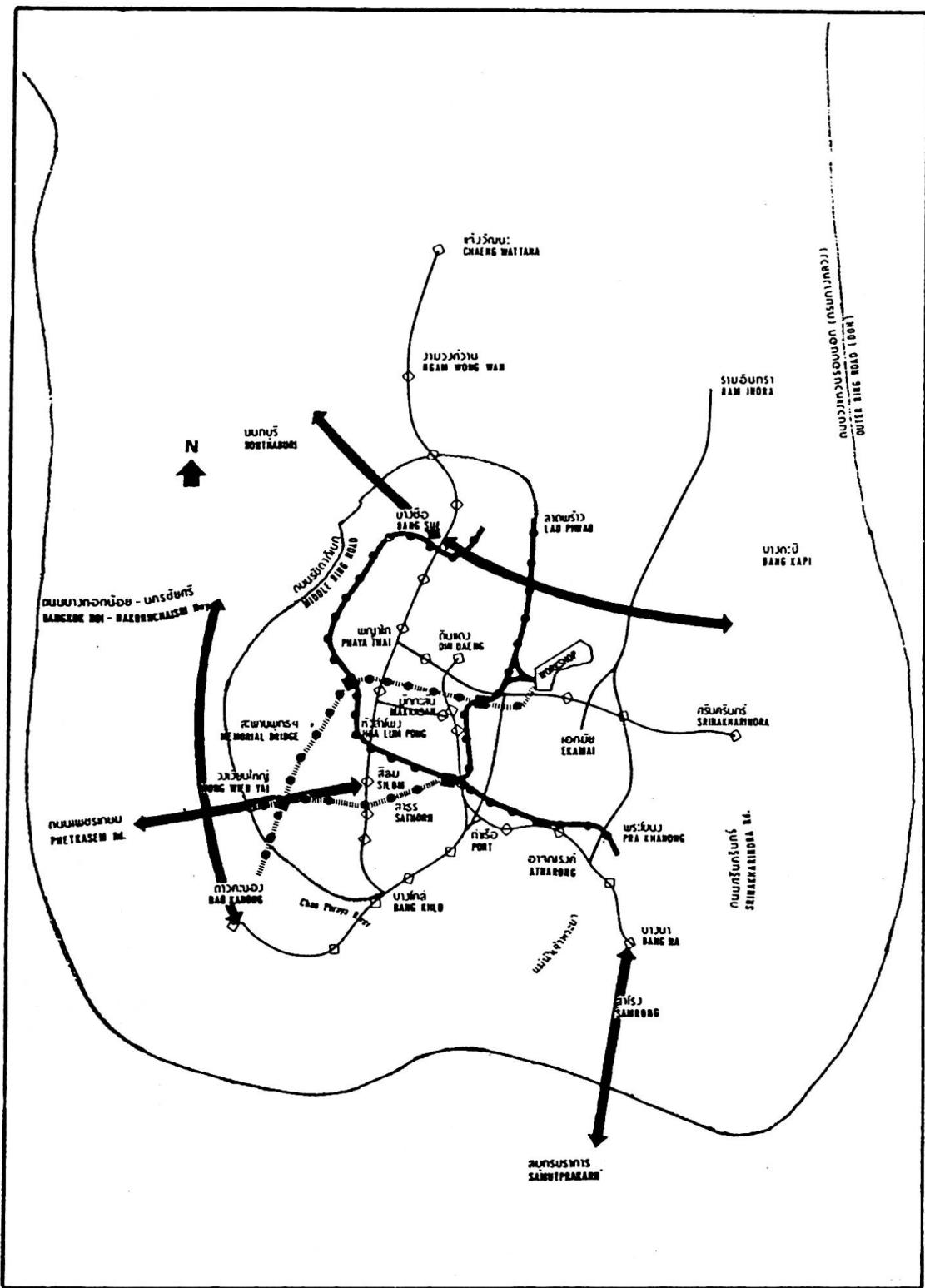


Fig.1 Expressway and Mass Transit System in Bangkok



## MAP OF PROJECT AREA

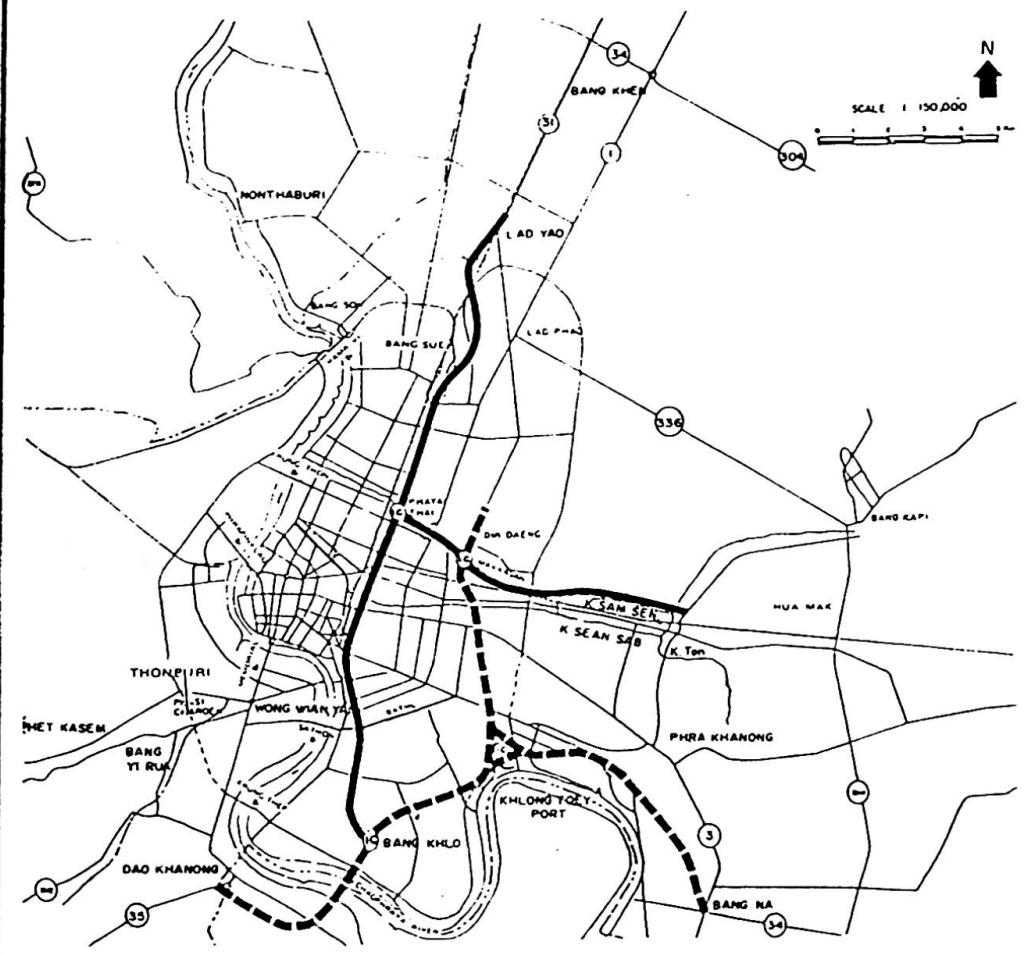


Fig.2 The Second Stage Expressway (SES)

## MANAGEMENT TEAM

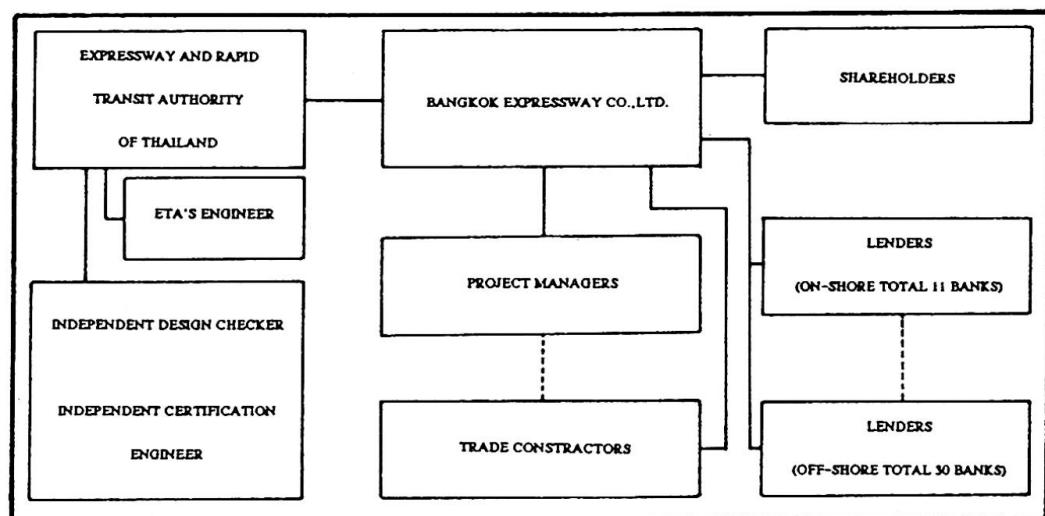


Fig.3 SES Management Team

## MASTER PROGRAMME

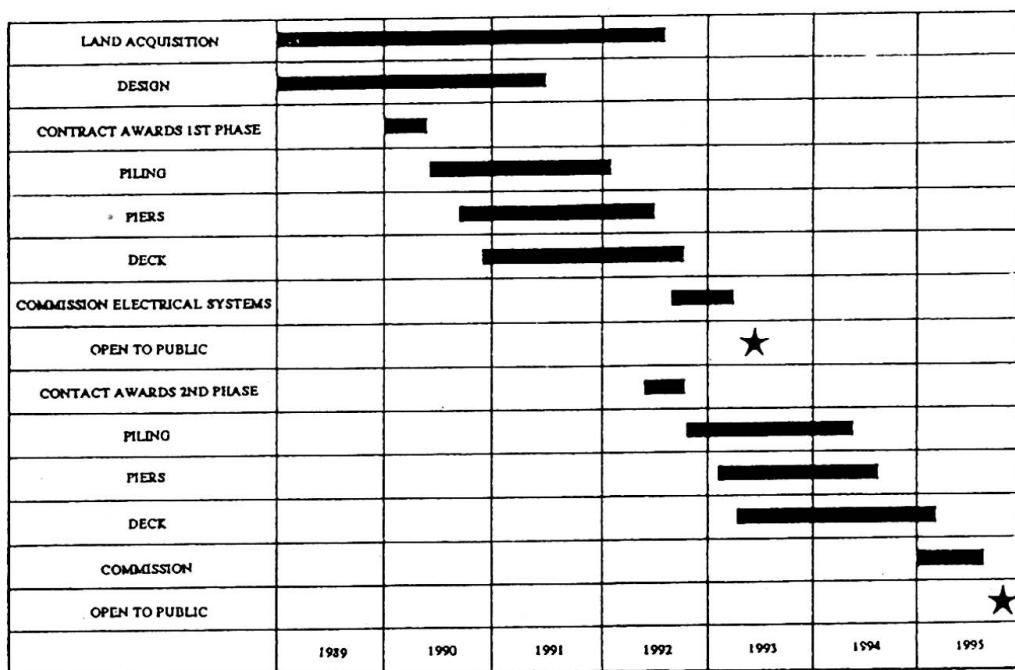


Fig.4 Master Schedule for the SES

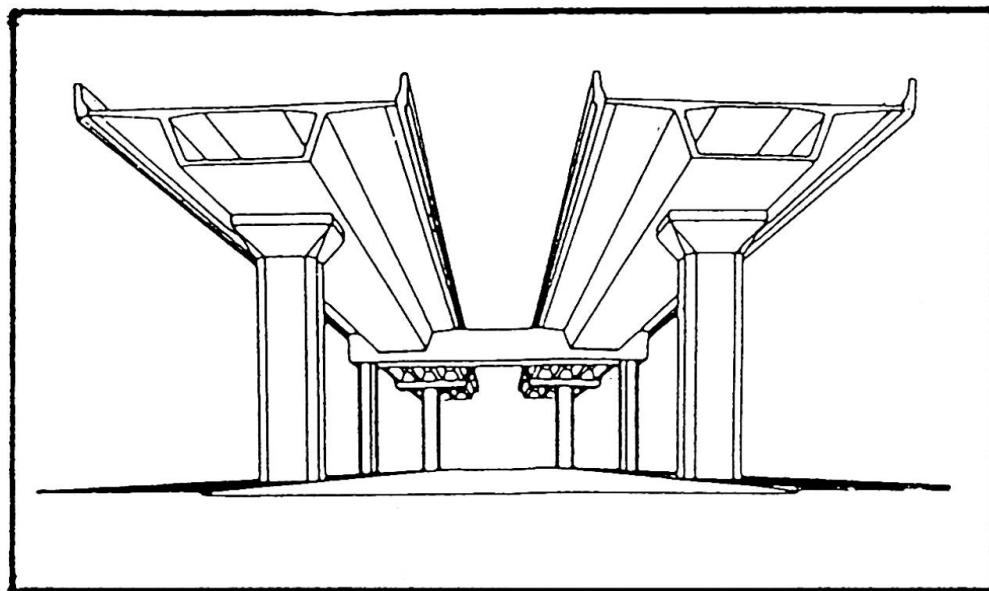


Fig.5 Segmental Box Girder

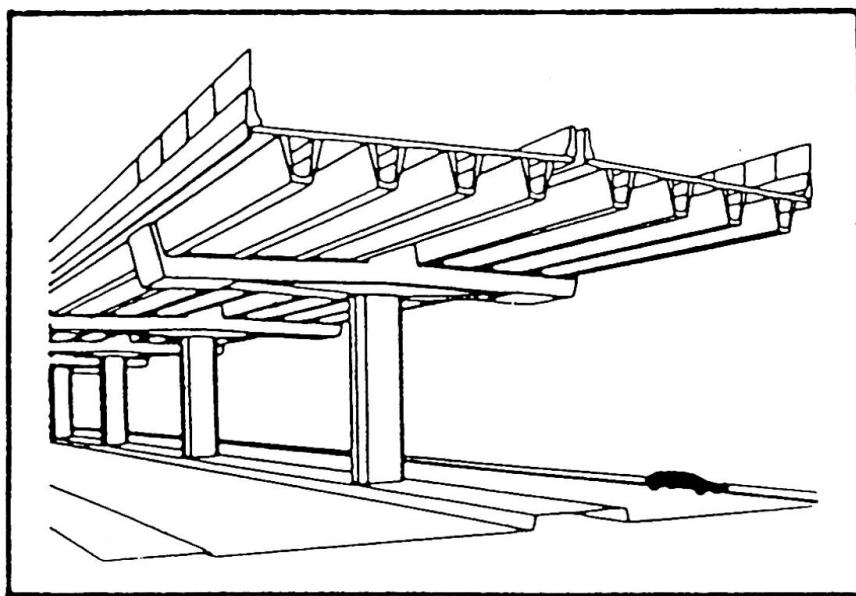
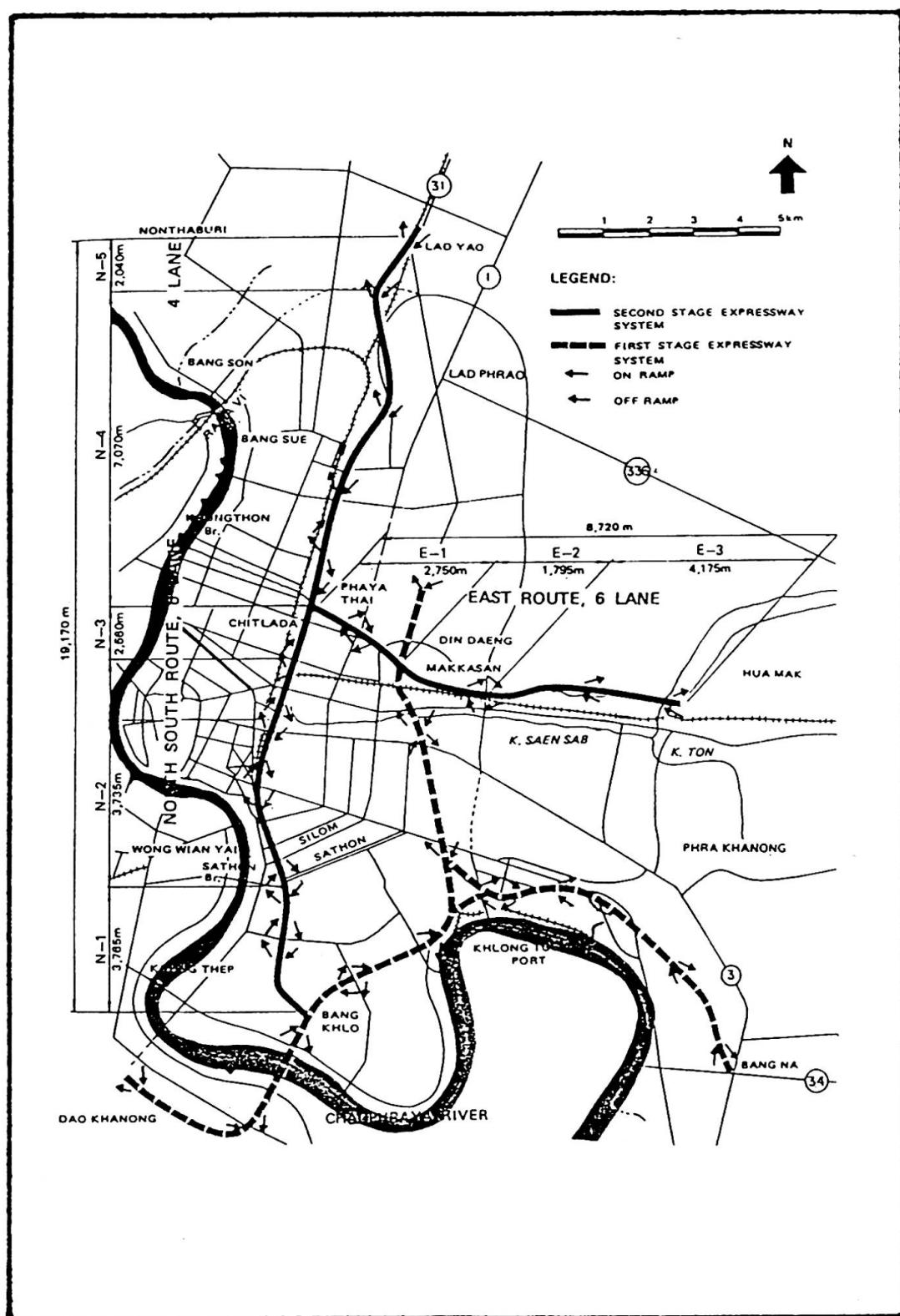


Fig.6 U-Beam Section



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## Rehabilitation of Transit Authority Structures in New York

Rénovation des structures du réseau urbain à New York

Sanierung von New Yorks Transportsystem

### **Mysore L. NAGARAJA**

Dep. Vice Pres.  
NYC Transit Authority  
New York, NY, USA



Mysore L. Nagaraja is a licensed Professional Engineer in New York and New Jersey. He has a Masters Degree in Civil Engineering. Presently he is responsible for New York City Transit Authority's multibillion dollar Capital Program. Mysore Nagaraja has 26 years of professional experience which includes 16 years in the field of transportation, bridge design and petro-chemicals.

### **Raza A. KHAN**

Div. Eng.  
NYC Transit Authority  
New York, NY, USA



Raza, A. Khan has over thirty years of engineering, research and management experience. A licensed Professional Engineer in New York and New Jersey, Raza Khan is presently responsible for the structural design of the NYC Transit Authority's multi-billion dollar Capital Programme.

## **SUMMARY**

The New York City Rapid Transit, the largest and oldest system of its kind in the United States of America, is being restored to a state of good repair. The capital investments in the rehabilitation of its infrastructure, is the only viable alternative to ensure that the system will continue to serve its 3.5 million daily customers. This article describes some of the more important rehabilitation work performed in the past several years.

## **RESUME**

L'administration du réseau urbain de New York – le plus ancien et le plus grand système de son genre aux Etats Unis – est en train de remettre en état son réseau routier. Les investissements pour la rénovation de l'infrastructure sont la seule alternative possible qui permette au système de continuer à desservir 3,5 millions d'utilisateurs quotidiens. Cet article décrit quelques-uns des travaux de rénovation les plus importants réalisés au cours des dernières années.

## **ZUSAMMENFASSUNG**

New York Citys' Rapid-Transit-System, das grösste und älteste öffentliche Transportsystem der Vereinigten Staaten, wird gegenwärtig in einen guten Unterhaltszustand zurückversetzt. Die Kapitalinvestitionen zur Sanierung seiner Infrastruktur sind die einzige mögliche Alternative, um die Gebrauchstüchtigkeit für seine täglichen 3,5 Millionen Benutzer sicherzustellen. Der Beitrag beschreibt einige der wichtigeren Sanierungsarbeiten aus den vergangenen Jahren.



## 1. INTRODUCTION

The New York City Rapid Transit System, the largest and oldest in the United States and one of the oldest in the world, consists of elevated, and subway track spread over the four boroughs of Brooklyn, the Bronx, Queens, and Manhattan. It carries an average of 3.5 million passengers per day. Over 5,000 subway cars carry one million passengers during every rush hour period, guided, controlled, and powered by 10,000 signals, 1,400 switches, 70 power substations, and 700 miles of track. Simply put - the New York City Transit Authority moves the people of New York.

The system was built in stages since 1885, bringing it to the present day level of completion. Considering the age, the system has maintained its status as one of the foremost systems in the world and has served the New York metropolitan area whose demands and expectations are diverse. This is probably the only system in the world that operates 24 hours a day, 365 days a year. The successful operation of a system of this magnitude and age requires viable solutions to the numerous problems encountered during its service life. The replacement cost of the system, in 1990 dollars, is estimated to be around 200 billion, not including the value of the real estate. Total replacement would be, therefore, out of the question. The only alternative is rehabilitation and properly scheduled maintenance.

We are moving towards a 21st century technology in terms of communications, signal systems, and cars. In order to readily accept this technology for operational use, all the tunnels and structures need to be rehabilitated and brought into a state of good repair.

The system comprises of a total of 230 route miles. Out of these 230 route miles, 123 miles or 54% of the system is underground. Another 37 miles or 16%, is in open cut, on embankment or on grade, while 70 miles or 30% is on elevated structures, which can properly be classified as continuous bridges. These 70 route miles include 181 track miles and 155 stations.

## 2. ELEVATED STRUCTURES

Some of the problems we face today on the elevated structures stem from the fact that most of the elevated lines were originally privately owned and operated. As a result we have structures of different size, of varying construction details, designed for lighter loads and less frequent operation, and meant to meet different social and environmental conditions. These factors compound the common maintenance concerns such as normal wear, corrosive attack by the elements, foundation settlement, fatigue failure, and obsolescence.



In order to understand the rehabilitation work, acquaintance with the nomenclature and the basic design elements of the elevated structures is necessary.

Foundations supporting the columns of the elevated structure are normally unreinforced concrete pedestal type footings, approximately ten feet deep, which support the elevated columns. Older columns are generally built-up sections. Today we use single wide flange members.

Rigidly connected by brackets to the tops of the columns are built-up members called cross girders. Attached to these, running parallel to the tracks, are built-up members called track stringers.

Clamped on top of the stringers are the cross ties which support the tracks. In addition to these basic elements, bracing, stiffeners, and expansion joints are provided as required. Design loads include a combination of dead load, live load, impact, wind, and traction loads.

## 2.1 Structural Rehabilitation

The Transit Authority utilized the services of a consulting firm to perform a study of the condition of our elevated structures. This study was completed in 1978 with the conclusion that the structures were generally in a good condition, but identified need for specific rehabilitations. This study complimented the Authority's periodic in-house inspection. Based on the in-house inspection and the consultant study, the following specific needs for rehabilitation were identified:

- o Column Replacement (Jamaica Line).
- o Rehabilitation of Steel (over mezzanines).
- o Rehabilitation of Track Supporting Members.
- o Rehabilitation of Expansion Joints.

### **2.1.1 Column Replacement**

On the Jamaica Line the Consultant found that, in an area near Crescent Street, the columns are overstressed by as much as 50% due to the loading from heavier cars used in the 1920s and 1930s. The original cars used on the Jamaica Line were constructed of wood, and were lighter in weight.

This line was constructed between 1888 and 1918, with several modifications made over the years. As a result, the line is not of uniform construction. In the section between the Van Siclen Avenue and Cypress Hills stations, a two track structure is supported on latticed columns comprised of four angles held together by lacing plates. In 1980 and 1982 the Authority awarded contracts totalling \$8.5 Million for the repair and modernization of this section. including the replacement of 192 columns.



The replacement procedure of columns was fairly simple. After suitable traffic barricades were placed, a timber grillage was laid on the street adjacent to the old column, to serve as a temporary footing.

Two 14" wide flanged columns were secured between this grillage and the cross girder above, to temporarily take the column load. Working from mechanized scaffolds, ironworkers removed the old column connections. Utilizing a telescoping crane the old column was removed, and a new wide flange column put in place and connected.

Following the removal of temporary supports, the column base was cast in concrete.

### 2.1.2 Rehabilitation of Steel (Over Mezzanines)

At stations on the elevated lines, the control areas and mezzanines are often hung from the structure, below the trackways. In lieu of track stringers in these areas we use thru-span girders, so called because the trains run between them. These thru-span girders rest on the top flanges of the cross girder.

In a thru-span area a system of floor beams support the concrete and steel track decks, which also serve as the roof of the mezzanine. While elevated lines generally avoid drainage problems by the use of open decks, these solid decks require a drainage system, which in turn requires maintenance in order to avoid the problems of clogged drains, ponding water, leakage, and corrosion. Areas where steel members protrude above the concrete deck are particularly susceptible to water intrusion and its attendant problems.

The drainage system which presently exists in many thru-span areas is largely dependent upon a series of short pipes which pass through the webs of existing beams. Being beneath the track and ties, these pipes are difficult to access and have tended to clog. Water backing up from these blocked drains has caused corrosion of the structural members and leakage along these members to the mezzanines below.

The new design being used at thru-span section consists of a structural slab, supporting the track concrete. The separation plane is waterproofed. Drainage is into the track troughs, to an inlet at the end of the thru-span section, and then by drains and leaders into the City sewers. Note that this is a much simpler system, much easier to maintain.

The corrosion of the thru-span girders caused by the malfunctioning drainage system is repaired by adding web plates to restore the strength of these members.



### 2.1.3 Rehabilitation of Track Supporting Members

Another problem we have on elevated structures involves the top flange angles of the track stringers. Between stations the track is supported on wood ties which rest directly on these top flange angles. Moisture, which is absorbed by or trapped under the wood ties, causes corrosion of the top flange angles. This corrosion is generally not visible until the ties are lifted. Depending on the extent and frequency of the corrosion, top flange angles are either spliced in the corroded area or completely replaced. New material is connected to existing using high strength bolts.

### 2.1.4 Rehabilitation of Expansion Joints

At approximately every 100 feet along the elevated structure, the connection of the track stringers to the cross girders provides for expansion. The seat bracket is composed of two angles with plates in between them and is attached to a cross girder. The rocker pin, a 4 inch diameter half round steel pin, slides on this seat bracket to allow for expansion. The track stringer is supported on the round part of the pin, allowing for rotation of the stringer. The constant sliding and rotating at this connection, coupled with corrosion, results in wear of the rocker pin and seat bracket. As this wear occurs, the top of this stringer will drop, causing a difference in elevation of adjacent stringers. This in turn results in excessive wear of the tracks. Under the Authority's continuing inspection program, these stringer elevations are recorded. When the difference in elevation exceeds  $1/4$  inch, replacement of the rocker pin is indicated.

The rocker pins presently are of carbon steel. We have switched to stainless to minimize corrosion, and to provide a smooth sliding surface.

Where the seat brackets have significant wear, we are replacing them with a newly designed seat bracket with stainless steel wearing surface.

## 3. SUBWAYS

The New York City Transit Authority's underground system includes the subway tunnels and other auxiliary structures. The subway tunnel sections are primarily of the following types:

- a) Circular cast iron tunnel.
- b) Concrete bent construction (Rectangular open cut section.)
- c) Steel bent construction (Rectangular open cut section.)

Auxiliary subway structures associated with the operation of the railroad and contiguous to the tunnels include vent shafts, emergency exits, equipment rooms, crew quarters, etc. The underground structures are generally



waterproofed to an extent that depends on the elevation of the ground water at the time of construction. The structures partially below the water table are provided with waterproofing under the invert and along the sides to a height above the ground water level. When the structures are totally below ground water and constructed in earth, they are completely waterproofed. If the invert is constructed in rock, the waterproofing is omitted and a non-structural slab is used with weep holes to relieve the water pressure.

In general, two types of waterproofing were used in the construction of the Transit Authority tunnels. The brick and mastic waterproofing was used for the most severe situations and consisted of bricks laid with a mastic mortar. The second type was the ply waterproofing which was originally made out of a coal tar product and a cotton fabric. The coal tar product later evolved into a petroleum based product. The tunnels presently in use by the Authority date back to the turn of the century. Due to age, deferred maintenance and changed conditions surrounding these tunnels, cracks have developed in the tunnel envelope. The presence of water outside, coupled with waterproofing that, in many instances, has become ineffective due to the passage of time, has resulted in water leaking into the tunnels.

The water infiltration corrodes reinforcing bars, structural steel, deteriorates line equipment, undermines the invert, overloads the drainage systems, deteriorates tracks, creates hazardous conditions for maintenance personnel and finally impacts on the operation of the railroad.

### 3.1 Water Remedy Work In Subways – History and Methodology

The extent of water infiltration depends on the causes and therefore, the approach to remedy the water condition must be tailored to suit the conditions. Substantial amounts of water infiltrating into the tunnels has required lowering the ground water level outside the subway tunnel. A number of contracts were awarded to install dewatering wells and well point systems to remedy the severe water infiltration problems on the Nostrand Avenue and Lenox Avenue Lines and at the Essex Street Station.

In locations where the invert has been undermined, cement grouting of voids as well as replacement of structural invert have been utilized as remedies. Cement grout was utilized to fill voids below the invert at Essex Street Station in 1982. A 275 foot length of structural invert replacement north of 42nd Street on the 8th Avenue Line was completed in 1987. A combination of cement grouting and invert replacement was completed in 1990 between 110th Street and 116th Street on Lenox Avenue.

Actively leaking cracks and damp patches of tunnel surfaces must be treated using methods that stop the water by filling in the cracks. Several products

and methods were utilized over the last ten years. A summary of products used on various contracts is provided in Table 1. The early attempts to stop water leaks were within the limits of the stations. These stations were part of the station modernization program. These projects utilized various types of cementitious repair products, such as Sika-set Plug, Master Builder Set-45, Five-Star waterproofing and Vulchem Sealant. To a large extent, these products were not very successful in sealing leaks. For example, the Contract for the rehabilitation of Bergen Street Station in 1982 utilized a combination of Sika cementitious plugs and a Five-Star cementitious coating to treat a severe water condition. This approach was not effective and Bergen Street Station was subsequently redone, years later, using chemical grout as part of the Culver Line Rehabilitation Contract. The original design of the first large water remedy contract on the 4th Avenue Line, while never awarded, specified cementitious grout and was subsequently changed to chemical grout by addenda.

### 3.1.1 Use of Chemical Grout

The Transit Authority's first exposure to chemical grouting was in 1968 when following the advice of Professor Chebetorial, approximately 200 ft of track invert north of Newkirk Avenue Station was grouted using AM9 grout. The objective was to grout the soil beneath the invert. The contract was terminated halfway through due to failure of the grout to stop the water inflow.

The Transit Authority initiated a program to perform structural rehabilitation of the subway tunnels in the early 1980's. These early contracts included water remedy work. In these contracts, an attempt was made to seal all cracks in the structure, leaking and non-leaking. The Transit Authority has utilized a number of consultants in developing and evaluating the use of various types of products to seal leaks.

In December 1982, a successful demonstration was performed at Metropolitan Avenue Station in Brooklyn utilizing a chemical grout to seal leaks. The product used was TACSS 020 polyurethane grout manufactured by DeNeef Construction Chemicals.

Transit Authority design projects subsequently specified the use of chemical grout. The contract for the rehabilitation of the 8th Avenue Line, advertised in 1985, was the first major line contract which utilized the TACSS 020 chemical grout. The contract for the rehabilitation of the Culver Line was awarded with TACSS 020 specified as the chemical grout. The contractor requested approval of Scotch Seal 5600, a polyurethane grout manufactured by 3M Construction Products in lieu of the specified product. The use of Scotch



CONTRACT NUMBER	DESCRIPTION	YEAR	PRODUCTS USED
C 30399	Rehab. of Bergen Street Station Borough of Brooklyn	1982	'Hey' Di Powder X 'Hey' Di Special Five Star Waterproof Plug Five Star W.P. Coating ('8")
T 31563	Repl. Tracks W8 St. To W32 St. 6th Ave. Borough of Manhattan	1983	Five Star Waterproofing Sika Set Plug Sika Top 123 Gel Mortar Hey Di K-11 Cement W.P.
Z 32271	Structural Improvement 4th Ave. BMT Line, Borough of Brooklyn	1984	Master Builder Set-45 Sika Set Plug Vulkem 116 Sealant
A 35553	Station Mod. of Kings Highway Station Borough of Brooklyn	1982	Sika Flex 1A
A 35522	Station Mod. of Church Ave. Station Borough of Brooklyn	1982	Sikadur 52 Epoxy Sealer Sikadur 33
C 20786	Archer Ave. Wrap Up Borough of Queens	1987	Acrylate AC 400
C 20167	Route 131A, Sect. 1 thru 7 63rd St. Tunnel Wrap Up Boroughs of Manhattan and Queens.	1988	Acrylate AC 400

Table 1 Record of Water Remedy Products

Seal 5600 was approved after a successful demonstration test at the Bergen Street Station. When the Authority was introduced to Scotch Seal 5600, the preparation of the new routes wrap-up contracts for the Archer Avenue and 63rd Street was under way. In these contracts, polyurethane grouts (3M Scotch Seal 5600 and DeNeef Flex 44LV) for large joints and cracks and acrylate grouts (Geochemical AC-400 and Celtite Terragel 55-31/32) for finer cracks were specified. Construction on these two contracts was completed utilizing both the polyurethane and acrylate grouts. Post construction feedback on both the 63rd Street and Archer Avenue contracts indicated that the acrylate grouts did not withstand the effects of wet-dry cycles and movements caused by seasonal changes. It was a result of this information that a decision was made in 1990 to utilize polyurethane grouts on all contracts.

### 3.1.2 Current Approach

At the present time, Transit Authority water remedy contracts are aimed primarily at sealing only active water leaks within the subway structures. The current specifications for chemical grouting to seal active water leaks designates the use of a polyurethane grout. These polyurethane grouts contain mainly urethane prepolymer and acetone. The polyurethane grout is pumped under pressure into the crack through drilled holes, reacts with water by foaming to form a flexible closed void solid which seals the leaking cracks within the structure.

This flexible closed void solid is capable of withstanding the movements of the subway structures caused by seasonal changes and train operations. In evaluating polyurethane grout, physical properties such as viscosity, solid content, density, tensile strength, elongation, shrinkage, etc. are considered. Two examples of the products currently being used are Scotch Seal 5600 manufactured by 3M Construction Products, St. Paul, Minnesota and Hydro-Active Flex LV manufactured by DeNeef Construction Chemical, Waller, Texas.

The contract specifications provide for grouting to be done in a series of up to three passes. The first pass seals all active leaks, the second pass seals new and migrated leaks and the third pass completes the sealing of any remaining leaks.

The quantity of lineal feet of leaking cracks is established during the design phase on the basis of a comprehensive field survey. The designers walk through the tunnel and record the location and the length of all the cracks. The total is increased to allow for new and migrated leaks. The field survey data which shows the location and length of cracks is made available to the prospective bidders during the bid period. A final inspection is made after



the contract is bid by a team made up of Authority and contractor personnel. In establishing grout quantities, it is estimated, based on past experience and input from the manufacturers, that one gallon of grout will seal three lineal feet of leaking crack.

The contract specifications include directions on handling, storage and disposal of the chemical grout as well as safety precautions to be followed during the grouting operation. The cured materials are essentially non toxic.

### 3.2 Other Rehabilitation Work

In addition to the water remedy work utilizing cement and chemical grouting, other significant rehabilitation work was performed in the subway structures to restore them to a state of good repair. This work can be divided into two categories - Work that is the result of water intrusion over the years and includes such items as repair of corroded structural steel and replacement of track. Work in the other category includes upgrading of the pump rooms, ventilation plants, and tunnel lighting. The work in the later category is also necessary to improve the efficiency, reliability and most of all the safety of the system.

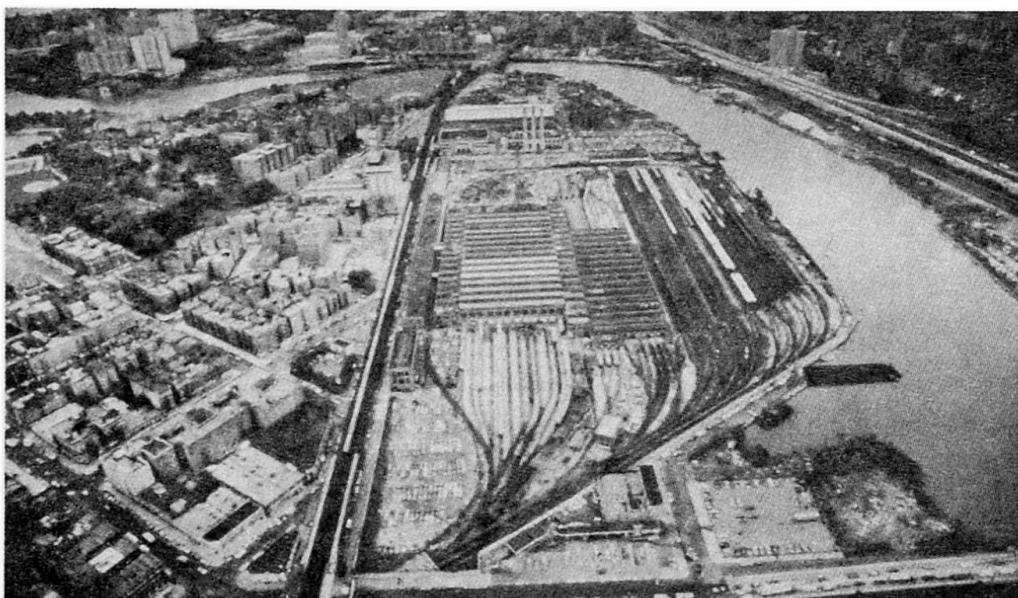
## **4. CONCLUSION**

The mission of the Transit Authority is:

"To achieve excellence in providing a safe, convenient, comfortable, reliable, cost effective, responsive, and customer oriented transportation system."

An infrastructure that is sound and in a state of good repair is essential to the safety and the reliability of the system, and would go a long way in accomplishing the mission of the Transit Authority.

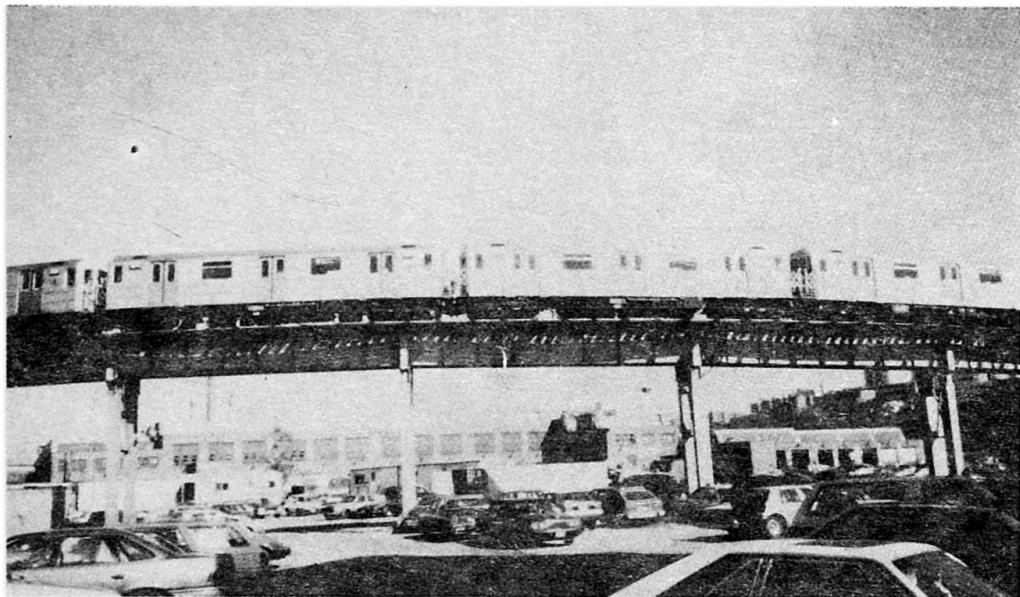
Over the last decade, the Authority invested substantial amount of money in the rehabilitation of the infrastructure. The return on investment is visible in a restored, reliable and vibrant system that is being noticed and appreciated by the riding public. More remains to be done to protect the earlier investments, and to retain the gains made to date. The 1992 - 1996 Capital Program, which envisions an investment of over seven and one half billion dollars in the rehabilitation of the line structure, stations, track, shops and bus depots, etc., is vital to the future of public transit operations in New York City.



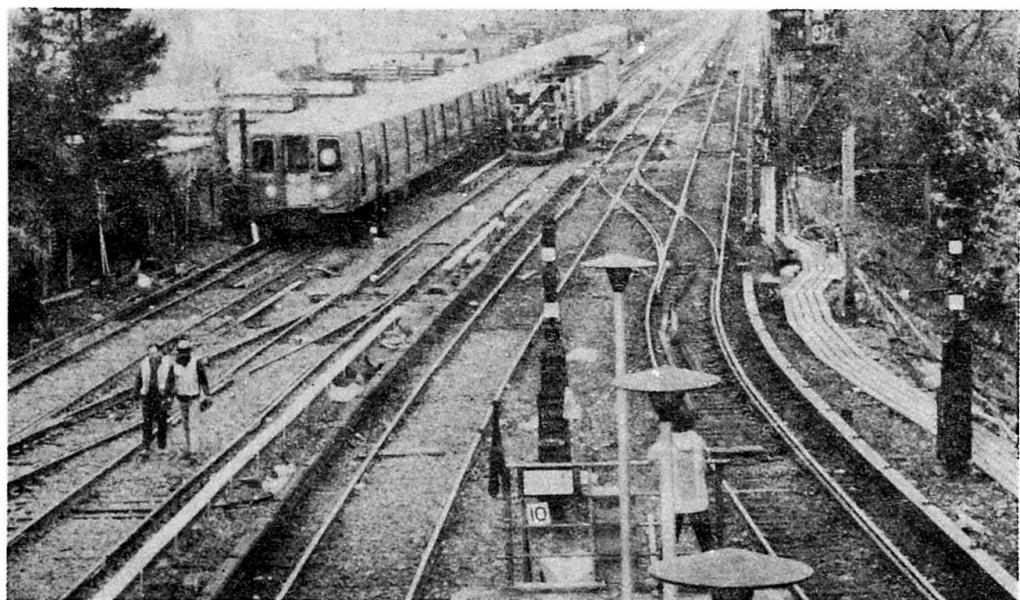
TRAIN STORAGE YARD



SUBWAY STATION



ELEVATED STRUCTURE



TRACK ON EMBANKMENT