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Case Histories: Geology, Value Engineering and Deep Foundations in New York Area

S. K. Jain
Sverdrup Corporation, New York, New York

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SYNOPSIS The geologic and subsurface conditions in the Metropolitan New York area are highly variable and complex. The Building Code of the City of New York (henceforth, The Code) requires soil identification based on their geological history and engineering characteristics. The code is very stringent and it specifies elaborate subsurface exploration, field testing and geotechnical analysis for the foundation design and its installation. In this paper three deep foundation construction case histories in the New York City are presented which emphasize the importance of site geology, subsurface exploration and value engineering.

INTRODUCTION

New York City is the largest city in the United States and is an important seaport on the east coast, as well as being one of the leading ports in the world. The city covers an area of approximately 360 square miles and is divided into five boroughs, i.e., The Bronx, Manhattan, Brooklyn, Queens and Staten Island.

What lies beneath the surface of the ground is of vital importance to the designers and builders of any engineered structures. The geology plays an important role in the planning and construction of such structures.

Due to the complex geology and variable subsurface conditions in the New York City area, a variety of deep foundation types have been employed to support the structures. The foundations derive their support ranging from glacial materials to bedrock. The bedrock qualities may vary from relatively sound to highly decomposed rock and could be from Manhattan Schist to soft Shale and Serpentine.

The pile types used in the area include steel H piles, pipe piles, monotube, Taper-Point-Tip (TPT), Enlarged Base Piles, prestressed concrete piles and caissons socketed into rock. The case histories in this paper describe the use of several of these foundations and emphasize the selection process of an optimum foundation type.

NEW YORK CITY GEOLOGY

New York City covers three physiographic units (the Coastal Plain; New England Upland and Triassic Lowland) which contain nine different foundation rock types and more than a dozen of soil units *(Figure 1)*. The physiography of the area had an influence on the pattern of development, transportation and urbanization. The New York area has gone through several geological processes (e.g., submergence beneath the sea, sedimentation, volcanism and mountain

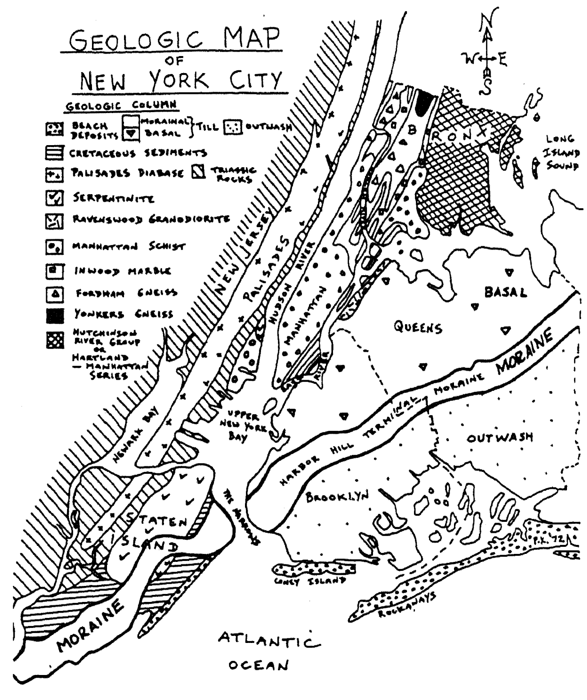

Figure 1: Geological Map of New York City

buildup, long-term and deep erosion, and so on) until finally the continental glaciation and the post glacial growth of coastal beaches.

The oldest rock in the region is the hard metamorphic Fordham Gneiss. It was originally laid down in layers, but at some early date in geologic history it was changed into folded black and white bands. Lying on top of the gneiss is the "Inwood Dolomite", a coarsely crystalline limestone. The most recent rock formation is known to be Manhattan Schist. There are numerous igneous intrusions found in the Inwood and Manhattan formations such as pegmatitic sills and dikes, and the Ravenswood Grand diorite. The Newark formation, a system of reddish-brown sandstones, shales and conglomerates, starts at the west side of the Hudson River, outcropping in Newark, NJ. The Palisade diabase is a great sheet of igneous rock which was intruded within the Newark group and extends from Haverstraw South into Staten Island. The serpentine, a metamorphic alteration product derived from igneous intrusion, covers a large part of Staten Island. Clay deposits, known as Cretaceous clays are found under the more recent glacial deposits of the south shore of Staten Island.

The northern part of New York City has been covered at least four times by the great ice sheets moving down from Labrador. The terminal moraine, which represents the southernmost extent of the last ice field, appears as a conspicuous ridge running from the north shore of Long Island, entering New York City in Queens, Brooklyn and crossing into Staten Island and Perth Amboy in New Jersey. It is generally believed that the ice front remained stationary for several thousand years before it retreated northward, dropping debris as it went back. In certain areas of New York City, it left great glacial lakes such as prehistoric Lake Flushing in Queens. To the south of the terminal moraine, the melting ice flowed southward, carrying with it sand, gravel and boulders, which dropped as it went along.

NEW YORK CITY BUILDING CODE DESIGN REQUIREMENTS

The design, construction and installation of foundations in New York City must conform to its building code requirements. These requirements are presented in detail in the appropriate sections of the code. The code has classified the soils and rocks into various categories based on their geological history and engineering characteristics. Each category of soil or rock is assigned an allowable bearing pressure which can be used for engineering analysis and foundation design. Therefore, the accurate soil and rock classifications are essential for foundation design to meet the building code requirements. The Soil and Rock Classification based on the code is briefly outlined in *Table 1*.

CASE HISTORY NO. 1: <u>PILE FOUNDATION IN STATEN ISLAND, NY</u>

PROJECT DESCRIPTION

The site is located on the eastern part of Staten Island, in Stapleton, New York and is approximately 2 miles north of the Verrazano Narrows Bridge, as shown in *Figure 2*. It contains approximately 40 acres of land along the Upper New York Bay. The property extends for a distance of approximately 5,000 feet along the Stapleton waterfront and varies in width from approximately 200 feet at the southern end to 500 feet at the northern end. The construction of this facility on this site includes an industrial maintenance and repair complex.

TABLE 1: <u>Building Code of the City of New York: Soil/Rock Material Classification</u>

Material Class	Description	Basic Allowable Bearing Values (Tons per sq. ft.)
1-65	Hard Sound Rock	60
2-65	Medium Hard Rock	40
3-65	Intermediate Rock	20
4-65	Soft Rock	8
5-65	Hard Pan	8-12
7-65	Sands (other than fine sands)	Ranges vary depending on various factors given in the Codes
8-65	Fine Sand	
9-65	SC, CL & CH	
10-65	ML/MH	
11-65	Unsatisfactory Bearing Material (e.g., Misc. Fill)	

SUBSURFACE CONDITIONS

The northern half of the Staten Island is covered by a thin to moderately thick mantle of superficial deposits, which belong to three glacial depositional land forms: ground moraine, terminal moraine, and outwash plains. Ground moraine consists of an unstratified reddish brown clay, sand and boulder till, predominantly derived from the Triassic shales and sandstones of the Newark Basin. The terminal moraine deposits have a composition similar to that of the unstratified deposit of the ground moraine, but are generally thicker. Glacial outwash deposits occupy a large portion of Staten Island. This deposits primarily consist of permeable stratified beds of reddish brown to gray sand and gravel. The site is underlain by glacial outwash and glacial till deposits. An ancient river travelled through the site during the pre-historic times.

A site location plan and simplified geological profile across the site is shown in *Figure 3*. As it can be seen, the fill and deposits of relatively recent materials overlie the compact glacial (G) soils. The flow of ancient river in the portion of the site created a valley by eroding the glacial till to elevation -70, which was subsequently filled with alluviual sands and organics. Also depicted in the profile is an inorganic silt of stratum (M). This silt stratum is believed to have been pre-loaded by the glaciers in the past.
The bedrock in this area is the Manhattan formation.

FOUNDATIONS ALTERNATIVES

As shown in *Figure 3*,there were six buildings constructed on the site with an area varying from 3000 to 203,000 sq.ft. The initial foundation alternative and design based on value engineering study is presented in *Table 2*.

The SIMA and Recreation/Exchange Building are next to each other with similar subsurface conditions.

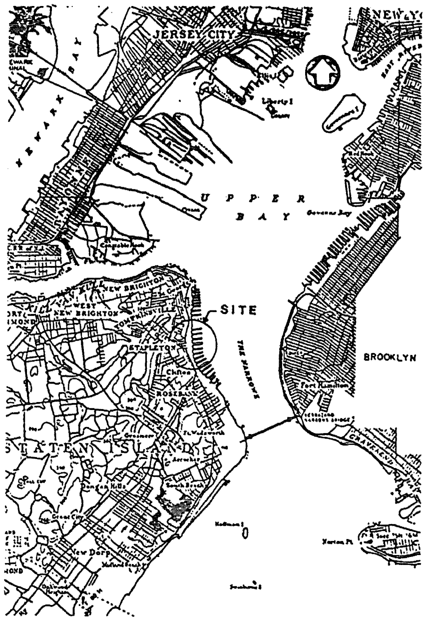

Figure 2: Site Location Plan

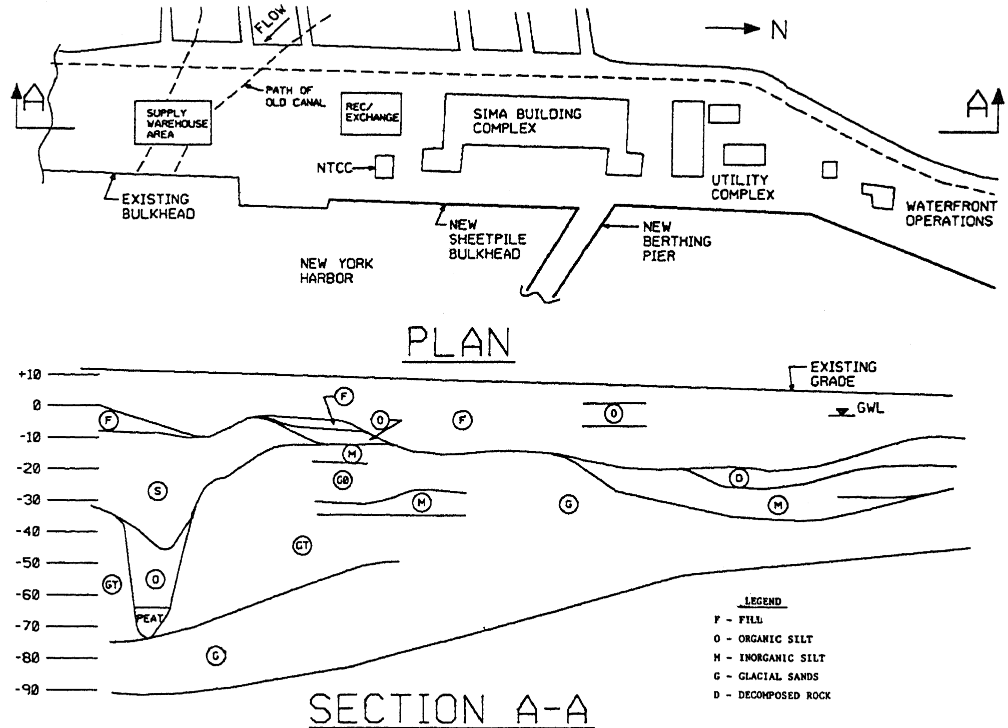

Figure 3: Plan and Subsurface Profile

Although SIMA is a much larger building, prestressed concrete piles, 16-inch square and about 65 feet long, with 80-ton capacity were selected to support these buildings. In a subsequent value engineering analysis of the piling during the construction contract negotiation, the TPT Enlarged Base Pile (See *Figure 3*) was found to be most economical and was successfully constructed.The TPT piles are proprietary piles (Underpinning and Foundation Contractors, Inc., New York, NY) with precast taper pile and are suitable to use in sandy soils (*Figure 4*). The TPT system consists of a pile stem of conventional material (shell), which is connected to a socket formed in the precast concrete Taper Pile Tip (TPT). This composite assembly is then driven as a unit by ordinary pile driving methods until a designated driving resistance is met in a suitable soil strata. This driving resistance is developed from the large tip size and densification produced by the TPT. Many combinations of tip shapes and stems are available to suit the specific requirements with respect to the subsoil conditions and pile capacities. TPT piles are essentially designed as end bearing and develop the required capacity with minimal penetration into the sand, thus providing the same capacity at shallow depth. The cost of TPT piles per ton of design capacity is considerably less than conventional piles and therefore proved economical during value engineering analysis.

TABLE 2: PILE FOUNDATION IN STATEN ISLAND, NY

	Preliminary Design			Value Engineering Study		
Structure	Pile Type	Design Load (Tons)	Bearing Material	Pile Type	Design Load (Tons)	Bearing Material
Supply Warehouse	Prestressed Precast Concrete (PPC)	80	G	Steel Pipe	80	G
Rec/Exch Bldg.	PPC	80	G	TPT (Tapered Point Tip)	80	G
SIMA Bldg. Complex	PPC	80	G	TPT	80	G
Utility Complex	PPC	80	G	PPC	80	G
Hazardous Waste and Waterfront Operations Bldg.	Timber	30	G	Timber	80	G

The Supply Warehouse is equipped with a high-stack, semi-automatic storage and retrieval system, which uses wire-guided man-up turret and order picker vehicles. A super-flat floor is required to provide

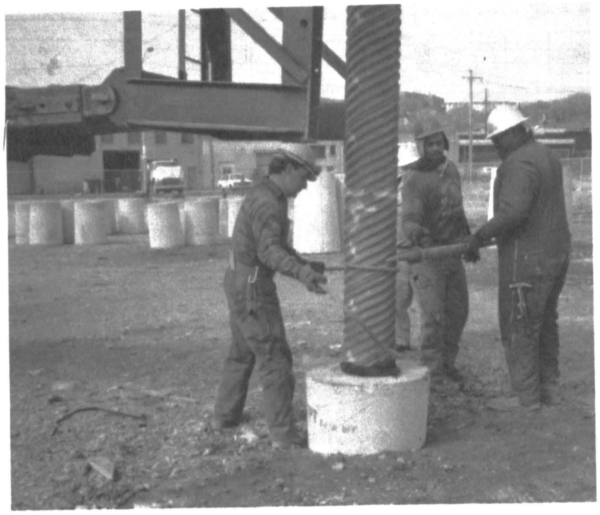

Figure 4: Installation of TPT Pile

stability for the man-up vehicles. Due to the variation in the elevation of the bearing strata, where the site was once occupied by the former riverchannel, steel pipe pile, 80-ton capacity and up to 95 feet long was chosen for this building. The other buildings were relatively small and were supported with 30 ton creosoted timber piles.

CASE HISTORY NO. 2: PILE FOUNDATION IN THE BRONX

PROJECT DESCRIPTION

The project consists of a Bus depot approximately 280,000 sq.ft and related Base maintenance facility located on a 33 acre site.
The site location is shown in *Figure 5*.

SITE GEOLOGY

The site lies immediately north of the terminal moraine that resulted from the Late Wisconsin Glaciation which completed its advance through the region approximately 20,000 years ago. The glacial lakes formed behind the terminal moraine as the ice sheet retreated, which completely submerged the site. Since drainage to the sea was blocked by the moraine, the silt, sands, silts and clays were deposited in varves. These varved soils generally overlay a glacial till deposited during the initial advance of the ice sheet. Sands overlaying the varved soils were probably deposited as the velocities of the water flow increased as a result of the lake being filled. Breaks in the moraine may also have occurred at this time which would tend to drain the lakes of fine soils. In recent geological times, the site has been a salt water marsh containing tidal estuaries draining into the Hutchinson River.

Figure 6 shows a generalized soil profile for the project area. The geologic profile indicates that the satisfactory bearing material exists somewhere between 20 to 30 feet below the ground surface. With groundwater table at 10 to 20 feet below the

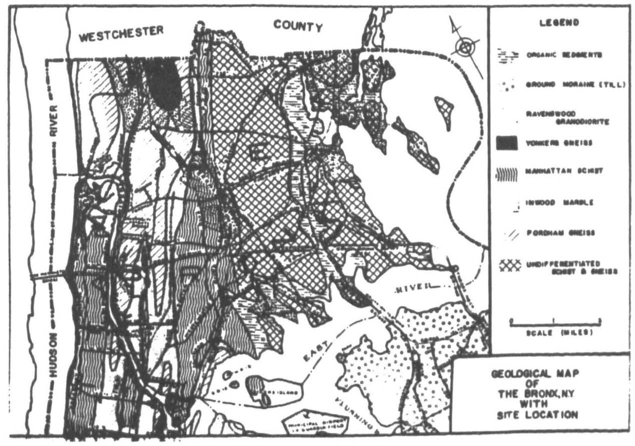

Figure 5: Geologic Map of Bronx

existing grade, it would require an extensive excavation, sheeting and bracing, and dewatering for a spread or mat foundation system. However, dewatering may cause settlement in the adjacent structures and utilities. It was, therefore, decided that deep foundation beused to transfer thebuilding loads to the deeper bearing strata. Several type of piles were considered. The engineering cost analysis were performed to evaluate the economic feasibility as well as the constructibility for each type of pile which are summarized in *Table 3*.

Steel H Piles bearing on rock was chosen for this project. Steel H piles are highly durable structural members and are suitable for bearing on rock. The advantage of an H Pile over other piles is its high capacity and ability to penetrate light obstructions. Their ability to penetrate obstructions was further improved by the use of a reinforced steel shoe at its tip.

In one corner of the site, the piles encountered considerable driving resistance to almost refusal before reaching the sound rock. This was due to an unanticipated, relatively thick layer of decomposed rock overlying the competent rock. The layer of decomposed rock in this area was confirmed during construction by making additional borings. Subsequently, pile load tests for 80-ton and 115-ton capacity were performed and driving criteria established for test piles driven to decomposed rock stratum. Upon completing the successful 115-ton pile load tests, the pile caps in this corner were redesigned for the 115-ton piles.

CASE HISTORY NO. 3: CAISSONS IN MANHATTAN, NY

PROJECT DESCRIPTION

Currently, Amtrak serves New York City through two facilities--Grand Central Terminal and Pennsylvania Station, separated by a distance of approximately 30 city blocks through highly congested midtown Manhattan. (See *Figure 7*). Thus, the "Westside Connection" was undertaken. The National Railroad Passenger Corporation (Amtrak), in an effort to simplify travel for its New York passengers, decided to consolidate its operations in New York City into one facility. The consolidation process involves the construction of a tunnel beneath congested city streets. The consolidation and construction included the rehabilitation of an idle 90-year old railroad swing bridge connecting the Bronx and Manhattan at Spuyten Duyvil, upgrading about 10 miles of an abandoned single track freight line and

TABLE 3: PILE FOUNDATION COST ANALYSIS IN THE BRONX, 1983.

Pile Type	Design Load (Tons)	Average Length (ft)	Cost Per Ton ($)
TPT	60	50	25
Compacted Concrete Piles	60	50	25
Cast-in-Place Concrete Pile Mandrel Driven	60	60	25
H Piles	150	100	32⁺
Pipe Piles (Open End)	80	70	40
Pipe Piles (Closed End)	80	70	35

construction of about a 1300 feet long tunnel on the west side of Manhattan leading to Penn Station. The tunnel alignment was along several existing elevated bridge and viaduct structures or adjacent to buildings. The existing structures are elevated structures resting on columns providing sufficient vertical clearance for trains at grade. Some of the columns supporting the streets were removed in making the tunnel. To protect the existing structures during construction of the tunnel, the columns supporting the 11th Avenue viaduct and the elevated plaza of the City's Convention Center required temporary or permanent underpinning. The basic underpinning consisted of transferring the column loads below the tunnel inverts. This was accomplished by installing caissons which were socketed into rock (*Figure 8*)

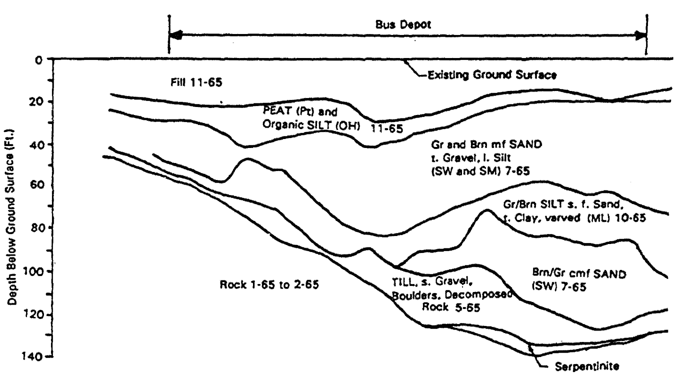

Figure 6: Subsurface Profile

A geological profile along the tunnel alignment prepared during construction is presented in *Figure 9*, which shows rock lines for(1-65) Hard Sound Rock,(2-65) Medium Hard Rock, and(3-65) Intermediate Rock.

Bedrock beneath the site is the Manhattan formation, a group of highly foliated schist, gneiss and quartzite which are characterized by the irregular fracture patterns and the variable weathering depths. However, the important feature in the profile is the variability of rock quality along the tunnel alignment.

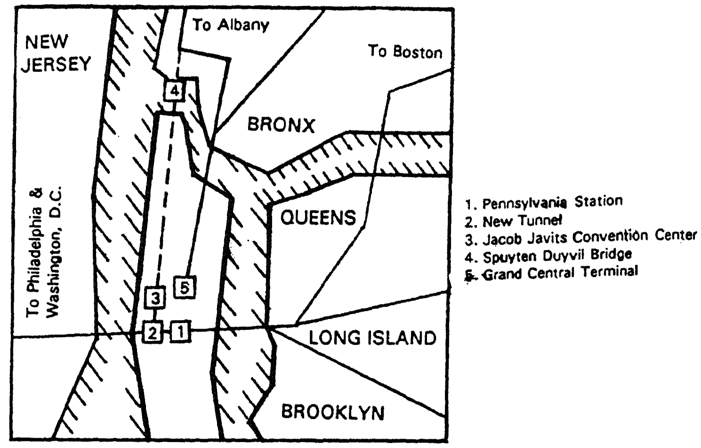

Figure 7: Site Location Plan

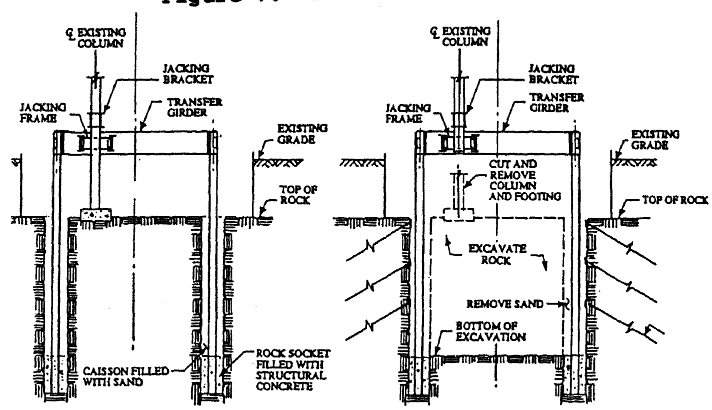

Figure 8: Use of Caisson in Underpinning

The caissons were originally designed to bear on 2-65 rock (40 tsf). The length of the socket was determined based on the end bearing and the side friction along the perimeter of the socket. The specifications required that the caissons be constructed from a 36-inch diameter hole above the structure subgrade and with a 24-inch diameter socket below the structure bottom. The specified caisson design and its installation procedures had to be modified during construction because of the following reasons:

- Unavailability of the drill rig to drill 36" hole under existing low overhead clearance.
- It is difficult to clean and inspect manually the 24-inch diameter rock socket for its quality.
- The size of rock socket was designed based on bearing on the 2-65 rock (40 tsf). During installation, the rock at many column locations were found to be poorer than 2-65. This would have required to drill deeper until the 2-65 rock is reached and would have delayed the project and incurred additional cost to the Owner.

A value engineering analysis was performed during construction. The diameter of rock socket was changed to 30 inches for bearing in 3-65 (20 tsf) rock. The diameter increase of the socket from 24" to 30" resulted in the same length of socket as would have required bearing on 2-65 rock. The revised caisson design, based on value engineering

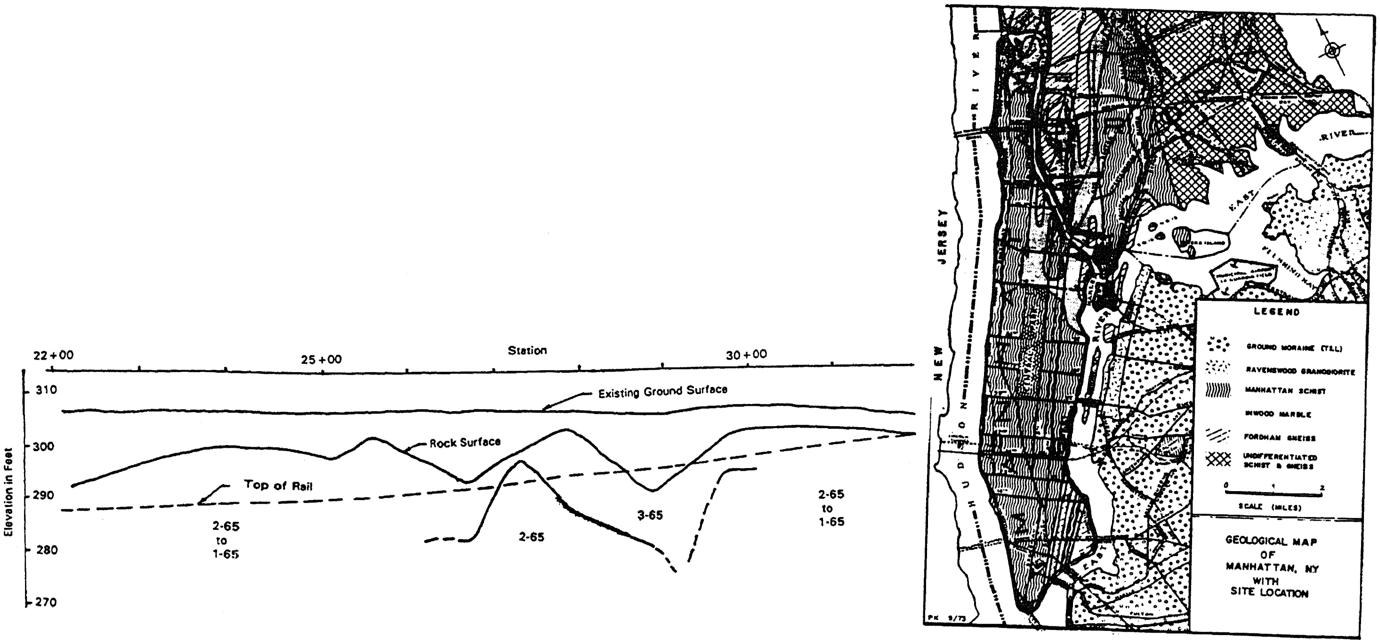

Figure 9: Subsurface Profile Along Tunnel Alignment and Geology of Manhattan

analysis, avoided a potentially costly delay in construction.

CONCLUSIONS

- The foundation design and installation in New York City must conform to the Building Code of the City of New York. The soil and rock are classified based on the geology and their engineering characteristics. Therefore, the understanding of site geology and behavior of the soils and rocks is essential to conduct geotechnical design and analysis.
- Common pile types employed in New York area include: Steel H Piles, pipe piles, TPT piles and caisson socketed into rock. Tapered piles such as monotube have been used advantageously in relatively loose granular soils. Auger cast piles are sometimes preferred and used at locations where construction vibrations are of concern to the soils and foundation of the nearby existing structures.
- Value Engineering analyses are often helpful in the selection of optimum foundation type, thus minimizing construction delays and ultimately resulting in savings for the owner.
- The utilization of the site specific geological and subsurface conditions through value engineering proved to be beneficial on the projects presented in this paper.

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