STRUCTURAL GEOLOGY AND THE PLANNING OF UNDERGROUND PROJECTS IN NEW YORK CITY, NEW YORK

Abstract

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There is approximately $50 billion dollars of proposed construction for major infrastructure projects in Manhattan for the next 20 years. Most of the projects include a substantial amount of tunneling and mining for transportation, water, sewerage and utilities. The successful design and construction of these projects requires a good understanding of the geology and engineering properties of the ground, particularly the fundamental structures. This presentation describes the difficulties of investigating structural geology in urban environments and methods that can replace the traditional rock outcrop. The investigation techniques that are currently in use have yielded a novel insight into tectonic structures and fracture patterns that confirm the basic hypothesis of structural orientation for the region and advance the knowledge of the fundamental geology of the Manhattan Prong, in particular the complex intercalation of the schist-marble contact.

Active studies include the Second Avenue Subway Project, the East Side Access Project, extension of the No 7 Line, the City water Tunnel, South Ferry Station improvements, Cross-Harbor Freight Tunnel. All of these are mega projects on a world scale that are forced below the ground surface for operational reasons, to reduce the environmental impact and avoid existing infrastructure. They include tunnels over 20ft in diameter to take subway and train cars, caverns up to 100 ft wide for stations and tunnels over 600ft deep for water supply.

The level of understanding of geological conditions is a function of how the site is investigated, how data are collected, assimilated, interpreted and communicated. If the ground conditions for a tunnel in rock are not addressed in this context the sophisticated design and mechanized construction available today are vulnerable to poor performance or failure.

This presentation will use examples to demonstrate the methods of collecting the geological data, how the interpretation of the structures is made and the importance of attention to geological detail.

The area is primarily comprised of the gneissic, amphibolitic Manhattan Schist and intercalated dolomitic marble and calcareous schists of the Inwood Marble. There are two major structural features: the Cameron Thrust Fault parallel to the long axis of the island and the Manhattanville-125th Street Fault, which obliquely cuts across Upper Manhattan (NW-SE), between 125th Street (west side) and 94th to 96th Streets (east side). The secondary fault/shear/fracture zones associated with these major ductile/brittle structural features have been revealed from recent subsurface investigations at many locations in the area. Extensive

pegmatite such as found between 12th and 57th Streets on the east side and amphibole rich schists are more common and thicker than perceived. Construction experience has shown that there are abundant faults from inch scale to shear and brecciated zones on 100ft scale that are not mapped. The fact that the rock is fractured is critical in itself but more importantly, when these fractures intersect in a certain way they create unstable conditions for construction of tunnels and deep open cuts (see Figures 1 and 2).

Figure 1. Typical excavated tunnel profile in Manhattan rock

Figure 2. Instability of re-entrant corner in deep excavation in Manhattan

Large-scale construction requires large-scale data for defining the geological structures but Manhattan is almost totally urbanized – even Central Park is landscaped extensively and includes false outcrops. Therefore the value of existing information from previous explorations in the area is very high. Old maps have proved to be particularly valuable sources because they can be used to undress urban Manhattan, but there is no substitute for physical evidence of the ground conditions.

The fundamental tool for exploration in Manhattan is the truck mounted rotary drilling rig (see Figure 3).

Figure 3. Truck mounted rotary drilling rig taking NQ cores

The method of logging samples from the coring has to be to a very high geotechnical standard because of the reliance that is placed on the data for design and contract purposes. Firstly, the core is logged as soon as it is removed from the core barrel (see figure 4). The cores are taken to a store where they are check logged by senior staff and samples are selected for lab testing – which are relogged after testing for mode of failure.

Figure 4. Core logging immediately after removal from core barrel

The quality of the material recovered in Manhattan varies dramatically (see figure 5 and 7). The fractured decomposed and chemically altered rock is the most difficult to log and classify but is possibly the most critical for construction projects.

Figure 5 & 6. Dramatic variation in quality of rock core recovered in Manhattan

The traditional method for directional control to orient features for structural interpretation in Manhattan is mechanical scribing of the core. However, the control scribe can rotate with the barrel and the system is particularly vulnerable in poor quality ground which is where the most control is required. A superior and increasingly popular method is the acoustic televiewer (see figure 7).

Figure 7. Acoustic televiewer sonde

The typical output from a televiewer survey is depth, dip and dip direction of a feature, the trace image and the reconstructed core using the borehole wall. This information alone does not tell you much because the image is an analogue but the core can be reconstructed and checked against the core in the box or very high quality digital photographs (see Figure 8).

Figure 8. Core sample (upper plate) and reconstructed core (lower plate) using televiewer image and. The dark areas are poorer quality, fractured or decomposed rock; the dark lines are open or infilled fractures.

The data from the televiewer outputs can be presented as stereographic projections and this example (see Figure 9) shows a classic Manhattan distribution of the three joint sets corresponding to fractures parallel to foliation, a steeply dipping set that strikes sub-parallel to the foliation and wraps in the dip direction – or maybe a curved surface, and the conjugate to the foliation fractures. These are usually referenced as Set1, Set 2 and Set 3 respectively.

Figure 9. Typical polar plot with great circles (Lower Hemisphere) for Manhattan schist

This provides the data for the planar features but faults and shears appear as zones of data rather than discrete planes. In these cases the orientation of the upper and lower surfaces of the structure are plotted as lower hemisphere polar projections (see Figure 10). The data show that the faults can be attributed to families and each family has sub-sets with characteristics. For example, Sz2 is the only sub-set in a large tract of eastern mid-town Manhattan that possesses clay gouge – indicating that this is a shear set. Family 1 tends to have evidence of open joints with no clay and little evidence of shear displacement – indicating a brittle extensional set.

Figure 10. Generalized polar plot and great circles (lower hemisphere) for faults in Central Manhattan

This type of information is currently being used to construct geological sections for significant lengths of Manhattan, particularly along the eastern side of the Island. The sections and maps will show the fundamental structure, the rock types and the contoured surface of the top of sound rock and the orientation and spacing of the joint system at many locations. These sections are a major, novel contribution to the geological knowledge of Manhattan, and their publication is anticipated in the near future.

The most profound conclusion from this work for underground construction in Manhattan is that the fundamental geological data have to be reliable and useful. It is possible to characterize the ground and make geological interpretations that have a direct and significant bearing on design and construction. The actual construction of the projects is eagerly awaited to correlate the predictions to the encountered structure.