Adjacent Structure Protection: State of Practice in New York City

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ABSTRACT
This paper presents the current state of practice in New York City (NYC) with respect to documentation, monitoring, and protection of structures adjacent to construction sites during excavation and foundation construction activities. The types of structures typically bordering construction sites, modes of their damage, and construction activities typically responsible for such damage are first discussed. The preemptive approach adopted by NYC regulatory agencies for protection of adjacent structures, their specific regulatory requirements, and common engineering practices are subsequently reviewed, followed by a brief discussion of recent advances in automated measurement and reporting systems.

1. INTRODUCTION
Building and infrastructure construction in densely populated modern urban areas, like New York City (NYC), faces significant challenges due to the presence of existing structures in very close proximity to the construction sites. NYC is famous for its lot-line construction practices, where new buildings are constructed directly bordering other buildings, tunnels, and other infrastructure. Construction activities, if not properly performed adjacent to these structures, can cause adverse impacts to these structures, which can in turn result in very expensive stop work orders, repairs, construction delays, and lawsuits. Learning from this experience over the past several decades, the NYC Department of Buildings (DOB) and other government-owned infrastructure agencies, such as the New York City Transit Authority (NYCTA), have established stringent mandatory requirements for investigation, documentation, and monitoring of structures adjacent to new excavation sites. Considerable effort is expended by developers and their engineering and construction teams to comply with these requirements and to ensure public safety.

2. TYPES OF ADJACENT STRUCTURES
Typically existing structures located adjacent to construction sites in the NYC include buildings, subway tunnels and stations, streets and sidewalks, and utilities. Buildings in NYC range from small 1-story structures to high-rise towers up to 100 plus stories in height. The low-rise buildings typically have none to one basement level extending 8 to 10 feet below the surrounding sidewalk level. The high-rise buildings routinely have 2 and sometimes 3 to 4 basement levels. Some of the low-to-mid-rise buildings are designated as “Historic Landmarks” based on their age, and historic and architectural significance. Landmarked buildings can be as much as 200 years old and can be very delicate. The low-rise buildings (less than 6 stories tall) are typically composed of load bearing brick/block/rubble walls and columns, and are supported on shallow foundations bearing on soil. The mid-rise buildings (7 to 25 stories tall) are typically load-bearing or framed structures supported on shallow or deep foundations depending on the sub-surface conditions in the area. The high rise buildings (taller than 25 stories) are typically framed steel or concrete structures supported on shallow foundations bearing on rock or deep foundations bearing on or socketted into rock.

Most of the shallower tunnels in NYC, located within 100 feet of the ground surface, belong to the NYCTA; this agency owns and operates the city’s underground subway system. A few other train and vehicular tunnels also exist and belong to agencies such as the Port Authority of New York and New Jersey (PANYNJ), Long Island Railroad (LIRR), Metro North Railroad (MNRR), etc. The tunnels and subway stations are typically located beneath streets in close proximity to the construction sites, while the associated vent structures and utilities are located beneath sidewalks that immediately border the construction sites.

3. IMPACT OF CONSTRUCTION ACTIVITIES
Construction activities can impact adjacent structures in three general modes: by direct contact, by causing ground movement, and by inducing ground vibrations. These modes and the associated construction activities are discussed below.

Direct Contact
The damage resulting from direct contact by construction equipment in motion can be severe. Severe damage can
also result during mechanical demolition of existing on-site structures directly connected to adjacent structures. Although severe, such damage is usually local. However, in past rare incidences, gross negligence during equipment operation, lack of equipment maintenance or improper erection of cranes, and improper demolition design and/or means and methods have lead to severe and more widespread damage to adjacent structures.

**Ground Movement**
Ground movement can be defined as unintentional movement or removal of soil or rock from beneath a structure resulting in its movement or loss of support. Ground movement can occur during site excavation, temporary excavation support or underpinning construction, site dewatering, etc. The obvious result is settlement of adjacent structures, which further results in cosmetic or structural damage and even collapse, depending upon the magnitude of settlement.

**Ground Vibrations**

*Low Magnitude, but Sustained Vibrations*
Low magnitude vibrations, that when instantaneous would not result in direct structural damage to adjacent buildings, can cause densification of loose or medium dense granular soils beneath adjacent structures over time. As a result, shallow-foundation-supported adjacent structures can undergo settlement, which can lead to their cosmetic or structural damage depending upon the settlement magnitude. Pile driving and rock excavation using hoe rams are examples of typical construction activities that can result in low magnitude sustained vibrations.

*Large Magnitude Vibrations*
Activities such as rock blasting, pile driving, and rock excavation using hoe rams when performed in close proximity to the adjacent structures can induce high vibration levels into the soil and rock supporting these structures. Depending upon the natural frequencies of the adjacent structures, and the frequency and magnitude of the induced vibrations, the adjacent structures can likely sustain various degrees of direct structural or settlement-induced damage.

4. **REGULATORY APPROACH & REQUIREMENTS**
In order to minimize the impact of demolition, excavation, and subsequent construction activities on the adjacent structures, the NYCDOB has adopted a pre-emptive approach of specifying stringent minimum requirements for performing site-specific investigation, design, permitting, documentation, inspection, and monitoring. Requirements pertaining to excavation and foundation construction activities are discussed in the paragraphs below.

**Investigation**
The quality of a design depends upon the accuracy of background information the design is based on. With respect to temporary excavation support and underpinning design for structures bordering construction sites, a reliable design cannot be made unless accurate information regarding the depths of the adjacent building basements and types and depths of their foundations is available. Therefore, the latest NYC Bldg Code requires that any temporary excavation support or underpinning design be based upon information obtained from a site-specific investigation of adjacent structures. Such an investigation typically consists of the following:

- Research and review of available information about the adjacent buildings. This information is available at the NYCDOB Records Room, on historic Sanborn maps, and on other public-domain web-based resources made available by agencies such as the NYC Department of Housing, New York Public Library, NYC Historic Preservation Commission, NYC Loft Board, and NYC Department of City Planning.
- Observations and select probes/test pits performed on-site and within the adjacent buildings to confirm field conditions.

**Design**
The NYC Bldg Code requires that temporary excavation support and underpinning be designed by a Professional Engineer licensed in the State of New York. Such a design professional is engaged either by the project developer/owner or by the excavation contractor. The design professional is required to submit signed and sealed copies of detailed site-specific excavation support and underpinning design drawings to the NYCDOB for their review and approval. In addition, the design professional is also required to submit signed and sealed copies of Technical Responsibility (TR) forms to the NYCDOB; these forms make the design professional legally liable for his design work and for the structural stability of the adjacent structures.

**Permitting and Notice**
The NYC Bldg Code requires the contractor to obtain an excavation permit from the NYCDOB. Depending upon the extent of the proposed excavation, additional requirements regarding temporary excavation support and underpinning design apply as discussed before. The developer/owner or the contractor is also required to provide sufficient notice to NYCDOB and the adjacent building owners prior to commencing earthwork at a site. The only exceptions to this requirement are excavation work less than 5 feet in depth performed anywhere on the site and excavation work between 5 and 10 feet in depth performed more than 10 feet away from the adjacent buildings.

When a construction site is located within 200 feet of any NYCTA subway structures, an approval from the NYCTA is required prior to commencing excavation and foundation construction work at the site as a pre-requisite to the NYCDOB work permit. Prior to performing dewatering operations, NYCTA approval is required for sites located within 500 feet of NYCTA structures. Similar notification and approval requirements also exist for the other mass transit agencies. In order to obtain such approvals, the project design and construction team is required to submit detailed design...
documents and construction means and methods for review by these agencies. Stringent constraints have been established by these agencies on construction means and methods that can be used in close proximity to their structures. For instance, the use of closed-end driven piles is not permitted within 10 feet of a NYCTA subway tunnel structure, and use of vibratory hammers and hoe rams is not permitted within 75 and 25 feet of a NYCTA subway tunnel structure, respectively.

**Documentation**

The latest NYC Bldg Code requires that prior to commencing any demolition or construction work, a physical examination and documentation of the adjacent properties be performed. The extent of such documentation depends upon the site influence zone, which for NYC Landmarked buildings is mandated to be 90 feet beyond the property limits per the requirements of NYCDOB Technical Policy and Procedure Notice (TPPN) 10/88. For other buildings, the influence zone is typically determined by the developer and their geotechnical and structural engineers based on the neighbouring building’s historic designation, the developer’s relationship with the neighbouring property owners, proposed depth of excavation, anticipated construction means and methods, and site sub-surface conditions.

The structural examination of the neighbouring buildings is performed by the project structural engineer or an independent structural engineer hired by the owner/developer or the contractor. Based on recommendations provided by the structural engineer, supplemental shoring and bracing is typically installed at the neighbouring buildings at the expense of the new construction project owner/developer. The geotechnical engineer typically performs a video and photographic documentation of the neighbouring building facades to document the pre-construction conditions of these facades in order to establish a baseline for comparison, should disputes arise at a later date. In addition, crack monitoring gauges are installed across select observed cracks, so these cracks can be monitored through the end of demolition and construction activities. Elevation and lateral position control points are also established at ground floor and roof levels of the neighbouring building facades typically at each corner of each building and at about 25 feet c/c in between.

For NYCTA subway tunnels, documentation is typically limited to the interior wall of the tunnel and adjacent tracks closest to the construction site, and any additional areas within a 1H:1V influence line extending up from the lowest proposed excavation level. The lateral extent of the documentation is typically limited to 50 feet beyond the limits of the construction site in each direction.

**Inspection**

Improper excavation and excavation support practices resulted in numerous building collapses in the outer boroughs of the NYC in the past decade. One of the main causes of such incidents was found to be lack of adequate oversight of the construction activities by a qualified engineer. As a result, in the last few years the NYCDOB has stepped up its efforts to enforce the inspection requirements stipulated in the NYC Bldg Code. The NYCDOB now mandates that all excavation, and temporary excavation support and underpinning construction activities must be performed under the controlled inspection (termed as “Special” inspection under the latest Code) of the Professional Engineer responsible for design of these systems. The NYCDOB requires that a qualified designated representative of the Professional Engineer be present at the site at all times to perform the controlled inspection work. After the excavation, and temporary excavation support and underpinning work is completed, the Professional Engineer is responsible for submitting the necessary signed and sealed TR forms to the NYCDOB certifying the work was performed under his/her supervision in accordance with the requirements of the design documents. Currently, the NYCDOB is in the process of establishing and enforcing more stringent qualification requirements for “Special Inspectors”, who can be allowed to perform these inspections on behalf of a licensed Professional Engineer.

**Monitoring**

Even if reasonable care is exercised during demolition, excavation, and construction activities, it is practically impossible to completely eliminate the impact on the neighbouring/bordering structures. What is important is to be able to monitor and quantify such impact, so it can be compared to pre-established conservative threshold limits, and remedial measures can be designed and implemented in time. Adverse impact to adjacent structures usually first manifests itself in the form of vertical or lateral movements of the structures or their facades and opening of pre-existing and/or new cracks. The approach to protecting the neighbouring structures is therefore to monitor the following:

- Vibration levels induced at the foundation level of the closest neighbouring/bordering structures.
- Elevations and lateral positions of the controlled points established during pre-construction conditions documentation.
- Appearance of new cracks and changes in the crack monitoring gauges established during the pre-construction conditions documentation.

The latest NYC Bldg Code mandates that whenever subsurface operations may impose loads or movements on adjoining property, the effect of such operations on the adjoining properties must be monitored. The monitoring requirements and thresholds are typically a function of the type and condition of the adjacent structure, and its historic designation. Commonly used guidelines are summarized below:

**NYC Landmarked Buildings**

The NYCDOB TPPN 10/88 provides the mandatory requirements and threshold values for monitoring of NYC Landmarked buildings within 90 feet of any excavation sites. Some of the important requirements are summarized below:
• Peak Particle Velocity (PPV) of vibration level at the closest Landmarked building must be limited to 0.5 inch/second, with no distance criterion.
• Any vertical or horizontal movements of the temporary retaining wall structures or neighbouring building facades must be limited to 0.25 inch. All survey measurements of the monitoring points are required to be made at least twice a week by a licensed Professional Land Surveyor to an accuracy of 0.01 feet.
• A micrometer sensitive to 0.001 inch must be used to monitor crack widths every day.

Non-landmarked Buildings
The NYCDOB sometimes requires relatively old and visibly fragile non-landmarked buildings to be treated as if landmarked for monitoring purposes. The monitoring and preliminary threshold level requirements for other non-landmarked buildings are typically determined by the Project Geotechnical Engineer of record in consultation with the Structural Engineer. As previously discussed, monitoring typically consists of vibration monitoring in the adjacent building basements, survey monitoring of vertical and lateral control points, and crack gauge monitoring. The typical vibration level threshold is established at a maximum PPV of 2.0 inches/second; this threshold is sometimes lowered based on other site-specific considerations such as condition of the adjacent buildings, anticipated sensitivity of the adjacent building occupants, and presence of vibration-sensitive equipment in the adjacent buildings. Although typical initial alert levels of 0.25 inch and 1mm are established for survey monitoring points and crack monitoring gauges, respectively, it is important to recognize that progressive trends in the control point and crack width data are better indicators of actual problems than the instantaneous readings themselves. Survey point and crack gauge monitoring is therefore performed at regular intervals, typically once a week and more frequently, as necessary, when construction activities are performed in close proximity to adjacent structures.

NYCTA Subway Structures
NYCTA typically requires a level-line survey of the railway track closest to the construction site to be performed to establish the initial position of the track. A final survey is typically required after construction is complete. Vibration monitoring of the subway wall is typically required at locations spaced approximately 25 to 50 feet c/c along the site and extending about 50 feet beyond the site limits. The mandatory vibration threshold level for the NYCTA subway structures is at a PPV of 0.5 inch/second. More stringent monitoring requirements and threshold levels may be mandated by NYCTA where substantially deeper excavations are planned or where vibration-producing activities in close proximity are anticipated over long periods of time.

5. AUTOMATED MONITORING SYSTEMS
Adjacent structure monitoring was traditionally done by performing manual readouts of the instrumentation. In recent years, with the increasing complexity of the construction projects and the associated increased risk, automated monitoring systems are gaining popularity.

A typical automated vibration monitoring system consists of a conventional seismograph connected to an alarm circuit and a wireless modem transmitter. Multiple vibration alert levels can be established such that when they are exceeded, the seismograph automatically transmits an alert message to an internet server along with the subject vibration data. The website is designed to immediately send out cell phone and e-mail alert notifications to pre-designated personnel. The server can also be programmed to download and publish the data on a website at periodic intervals for review by pre-designated members of the construction team. Such systems are now almost mandatory for construction sites adjacent to sensitive Landmarked structures and NYCTA subway structures, and on large infrastructure projects.

Automated Monitoring Theodolite System (AMTS) now replaces manual survey monitoring on several complex projects. The system consists of a series of automatic theodolites installed beyond the site influence zone and programmed to monitor multiple targets installed on the adjacent building facades in a near-continuous manner. The data is transmitted frequently to an internet server, where it is processed, uploaded, and displayed on a website in the form of user friendly charts; the website is made accessible to pre-designated members of the construction team. The AMTS system can also be set up with multiple alert levels, such that when the recorded movements or the rate of change of movement exceed the pre-designated threshold levels, the website transmits cell phone and e-mail alert messages to pre-designated recipients. Similar automated systems are available for crack and building tilt monitoring.

Although the initial set up cost for such systems is relatively high, these systems prove to be cost effective on projects where multiple structures need to be monitored on a daily basis over a long duration of time. The advantages of the above-mentioned systems over manual readout systems are: increased frequency of measurement at a relatively lower cost, increased measurement precision, significant reduction in reporting and response time, and better risk management for the project owner.

6. CONCLUSIONS
This paper presents an overview of the current regulatory requirements and state of practice for protection of structures adjacent to excavation sites in NYC. These requirements and procedures have evolved through lessons learnt over the years. As the high-rise markets in Indian metropolitan areas such as Mumbai, Hyderabad, Bangalore, Chennai, etc. continue to mature, and the density of high-rise buildings and the depths of their foundation excavations increase, the local regulatory, development, engineering, and construction communities should adopt these state of the art requirements and procedures as part their local practice.