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City required instrumentation and how it impacts engineering practice

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Abstract

In New York City (NYC), USA, revisions to the NYC Building Code in 2014 created significant changes to the amount and type of instrumentation monitoring required during development of almost all construction projects that included excavation. These revisions were prompted by several construction site deaths that occurred during the building boom in the mid-2000s and were developed with peer involvement by the local engineering industry as well as input from significantly increased professional staff hired by the NYC Department of Buildings.

The NYC Building Code instrumentation monitoring requirements encompass the monitoring of vibration and horizontal and vertical displacement, as well as the requirement for pre-construction condition documentation. For the most part, the requirements do not establish a framework for quantities, set threshold limits, or specify monitoring reading frequency; these monitoring program components are developed by the Professional Engineer responsible for the project excavation elements. Where Landmark or Historic structures are directly adjacent or within a 90-foot (27.43-meter) distance from the new construction, additional requirements are enforced. In these cases, a NYC mandate promulgated in 1988 provides specific requirements for pre-construction condition documentation and, among other requirements, the establishment of displacement and vibration limits.

The 2014 NYC Building Code changes very quickly resulted in a surge of new work for the small number of existing specialty instrumentation and geotechnical engineering firms that had historically undertaken instrumentation work, which then spurred the creation of more specialty instrumentation firms.

This paper will provide further insight and discussion of these mandated instrumentation requirements and will provide in-depth discussion by the authors, practitioners in the NYC engineering and consulting markets, as to how this has changed the instrumentation market and practice.

Keywords: Instrumentation, Monitoring, Prescriptive Monitoring Requirements, New York City, TPPN 10/88

1. Introduction

Promulgated and enforced by the NYC Department of Buildings (NYCDOB), the current (2014) NYC Building Code (NYCBC), Section 3309 outlines the requirements for protection of adjoining buildings and property from damage during construction, demolition, and excavation activities. Section 3309 includes requirements for preconstruction documentation and monitoring of adjacent structures with below grade excavations beyond a depth of five feet (1.52 meters) or within a 1:1 influence line of the excavation. In addition, the NYCDOB Technical Policy and Procedure Notice #10/88 (TPPN 10/88) outlines the documentation and monitoring requirements for adjacent structures located within NYC Landmarks Preservation Commission (LPC)-designated Historic districts or Landmarks within 90 feet (27.43-meters) of the project property line.

Given the dense urban environment of NYC, most construction projects are undertaken on relatively small properties with limited footprint where the buildings below grade levels (cellars and basements) are built up to the actual property lines. Where proposed buildings directly abut adjacent buildings/property lines, NYCBC requires one inch (2.54 cm) of separation for each 50 feet (15.24 meters) of total building height to create a seismic gap above the street level. Often, these building projects are within Historic districts where the building facades must remain and vertical expansion is limited; owners will often opt to deepen existing building cellars, sometimes with hand-excavated underpinning to depths of 25 feet (7.62 meters) or more.

Where there are rear yards or open lots with abutting buildings at the lot lines, various drilled excavation support systems such as secant piles or soldier piles and timber lagging can be used as a method of soil retention. The installation of support elements, excavations, and underpinning trigger NYCBC requirements for instrumentation to monitor adjacent buildings.

In this paper we will discuss the various code-related requirements for preconstruction documentation and monitoring of adjacent buildings and infrastructure, how these regulations and requirements came to be, and how they have impacted the local geotechnical and instrumentation practices.

2. History of Historic Landmark Preservation and New York City Building Code

Technical Policy and Procedure Notice 10/88 (TPPN 10/88) was enacted into NYC Local Law in 1988, titled "Procedures for the Avoidance of Damage to Historic Structures Resulting from Adjacent Construction When Subject to Controlled Inspection by Section 27-724 and for Any Existing Structure Designated by the Commissioner." The intent, as summarized in the background section of the document is to "require a monitoring program to reduce the likelihood of construction damages to adjacent historic structures and to detect at an early stage the beginnings of damage so that construction procedures can be changed."

Among other procedures, the following criteria were included in the 1988 law:

Establish a Construction Monitoring Program (CMP)

Maximum Peak particle velocity of 0.5 inches per second (13 mm/sec), to be reduced if movement or cracking is detected

Establish criteria for temporary retaining walls (support of excavation), with maximum movement designed in accordance with "generally accepted engineering practice"

Maximum permissible movement of historic structure of 0.25 inches (6 mm), monitored by licensed surveyor for movements and tilting of historic buildings and retaining walls

Establish groundwater monitoring criteria, and measure water levels twice daily during dewatering

Monitor settlement of streets and points on the ground

Survey a minimum of twice per week to an accuracy of 0.125 inches (3 mm)

Install crack gages on existing cracks, measured daily to nearest 0.001 inches (0.003 mm)

Photograph historic structures weekly, with sufficient clarity to view cracks

Retain records of the monitoring and controlled inspection reports, submitting to the NYCDOB within 30 days of completion of excavation

These criteria were intended for all Historic Districts and Landmarks located a within horizontal distance of 90 feet (27.43-meters) from the property line of a construction site.

The authors underwent a search of the history or derivation of the above criteria or events which may have contributed to establishing these criteria as such was not initially obvious or known amongst most practitioners we interviewed, including those at the Landmarks Preservation Commission or the Department of Buildings. [Email correspondence between Volterra, Joel of MRCE and Weiss, John and Herrala, Cory of NYC LPC, on March 28-29, 2022.] Further research and tracing of references led us to the 1981 paper titled "Avoidance of Damage to Historic Structures Resulting from Adjacent Construction", by Melvin Esrig and Andrew Ciancia published by ASCE in New York, NY in 1981. The paper summarizes the author's experience designing and monitoring construction effects of a 29-story office tower at 85 Broad Street in the lower Manhattan historic district in the early 1980's. The paper describes the methodology the project team underwent to establish the criteria for vibrations, crack monitoring, groundwater monitoring and optical survey, which later served as the direct basis for TPPN 10/88.

TPPN 10/88 influences a significant portion of ongoing development within NYC as these are often the most valuable and sought-after locations for development and construction. According to the LPC website, "there are more than 37,600 Landmark properties in New York City, most of which are in 152 historic districts and historic district extensions in all five boroughs. The total number of protected sites also includes 1,445 individual Landmarks, 121 interior Landmarks, and 11 scenic Landmarks." LPC designated just under 5,600 sites as Landmarks in its first five years of existence. An additional 7,400, 4,500, and 5,400 sites were designated as Landmarks in the 1970s, 1980s, and 1990s, respectively, as indicated below. LPC continues to designate Historic properties and establish ne districts.

Time Frame	Number of Landmark Sites Designated
1965-1970	5,594
1970s	7,356
1980s	4,524
1990s	5,432
2000s	4,594
Since 2010	10,100*

*Total since 2010 computed from 37,600 total number listed on website minus total tabulated above for time periods from inception.

Table 1: Designated Landmark Sites 1965 through Present. [Ref: https://storymaps.arcgis.com/stories/981732666b194d63ab291a64b9543080]

Prior to 2014, NYCBC monitoring requirements outside of TPPN 10/88 were essentially left to the discretion of the design professional. The 2014 NYCBC made significant changes to the amount and type of instrumentation monitoring required during development of almost all construction projects. These revisions were prompted by several construction site deaths that occurred during the building boom in the mid-2000s and were developed with peer involvement by the local engineering industry as well as input from significantly increased professional staff hired by the NYCDOB.

Changes strengthened monitoring programs by requiring that copies of monitoring plans and other records be kept on-site and made available upon request. The revised code further required that monitoring plans be designed by the registered professional where excavation, foundation construction or underpinning is required. The monitoring plans were to be specific to the structures to be monitored and the operations to be undertaken; the plans were to specify the scope and frequency of monitoring, acceptable thresholds, and reporting criteria if thresholds were exceeded. At a minimum, all structures within a 1:1 influence line of the excavation were to be monitored, as well as any Historic district of Landmark structures within 90 feet (27.43 meters). A physical examination of the adjacent property was to be made, with a 60-day written notice provided to the adjacent property owner prior to start of work.

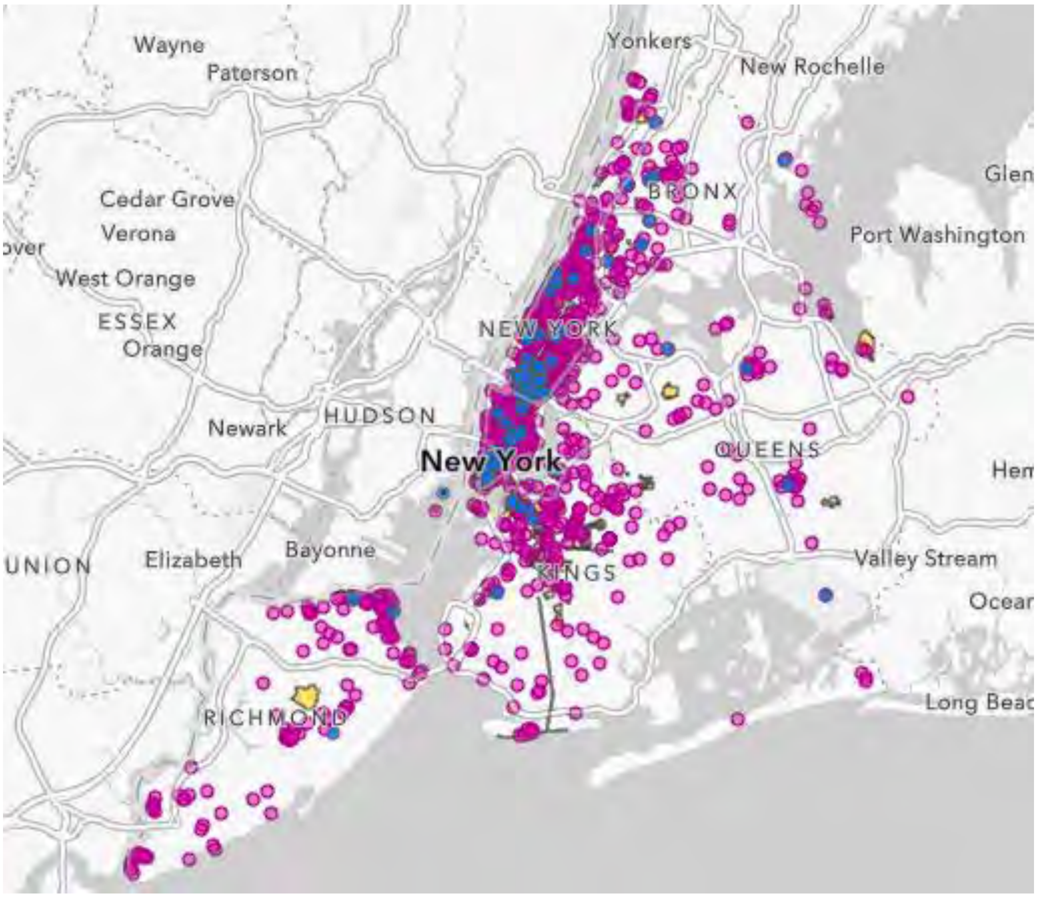

Figure 1: Landmark Preservation Commission Mapping of New York City Landmarks [Ref: https://www1.nyc.gov/site/lpc/designations/maps.page]

3. Other Agencies

In addition to the NYCBC, several infrastructure agencies that have jurisdiction over tunnels or bridges within NYC have prescriptive monitoring requirements or require the design professional to provide an instrumentation and monitoring program if the proposed construction is adjacent to their facilities. NYCDOB drawing or permit submission can trigger review by agencies in the case where multiple parties exist within the area of influence of the project. These agencies include:

- NYC Department of Transportation (DOT) - Site Specific
- Long Island Railroad (LIRR) – Site Specific
- Metro North (MN) – Site Specific
- Port Authority of New York and New Jersey (PANYNJ) – Site Specific
- Metropolitan Transportation Authority – New York City Transit (MTA NYCT) – Prescribed

The most stringent of these agencies and the most often encountered is MTA NYCT, which requires extensive vibration monitoring within its tunnels and on above ground elevated structures for blasting, pile installations, and excavations within their influence including:

- Before the start of work, perform an examination of the interior and exterior of NYCT subway or other structure adjacent to the proposed work
- Vibration monitoring sensors are required on 25 foot (7.62 meters) spacing on nearest track and/or tunnel wall of elevated structure, at a minimum, expanded to cover adjacent tracks or maintenance areas or vents within or adjoining NYCT tunnels where lines or tracks are double height or cross over one another, at discretion of reviewer

- Level line survey to baseline elevation profile is required:
  - Routine optical deformation monitoring is rarely required within tunnels
  - Optical deformation standard for above ground elevated structures, for every column within influence, is required at discretion of reviewer
- Strain gages required on oldest, most sensitive of cast-iron tube tunnels

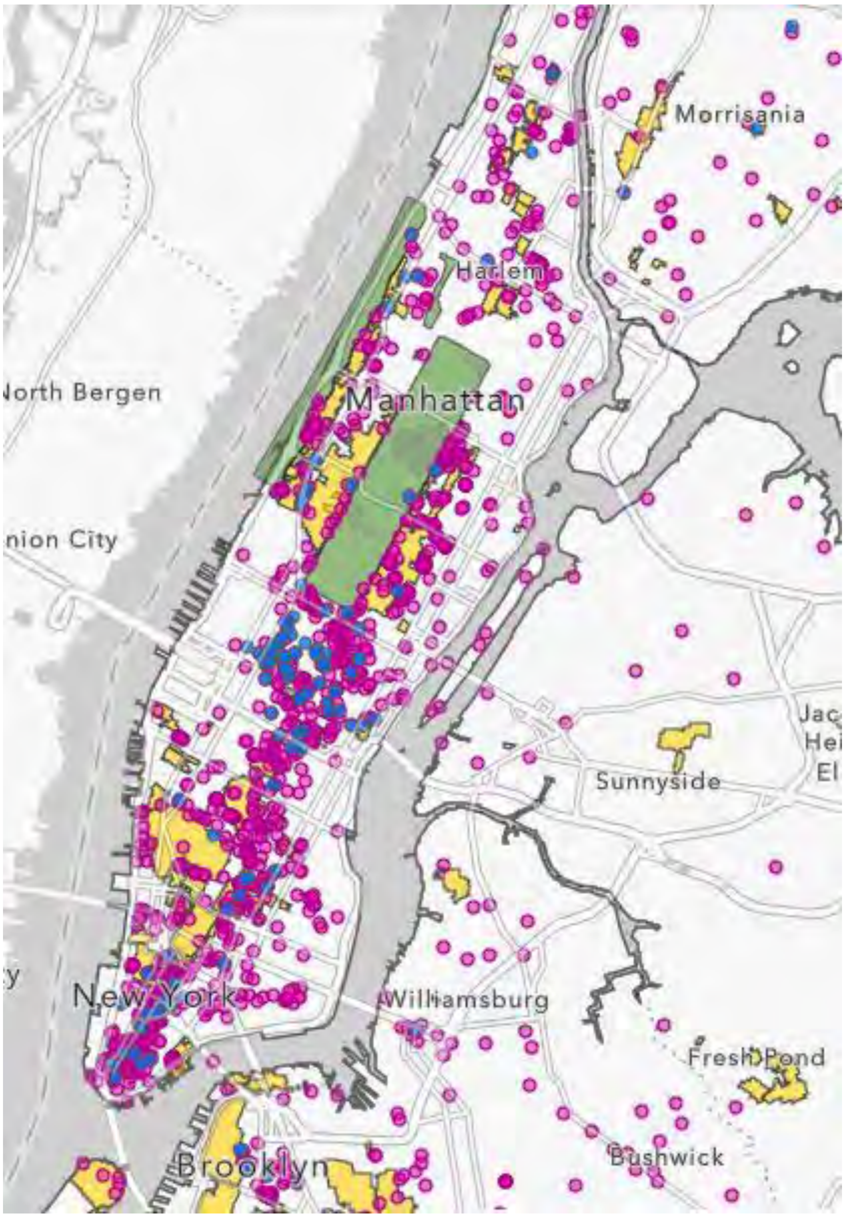

Figure 2: Landmark Preservation Commission Mapping of Manhattan Landmarks

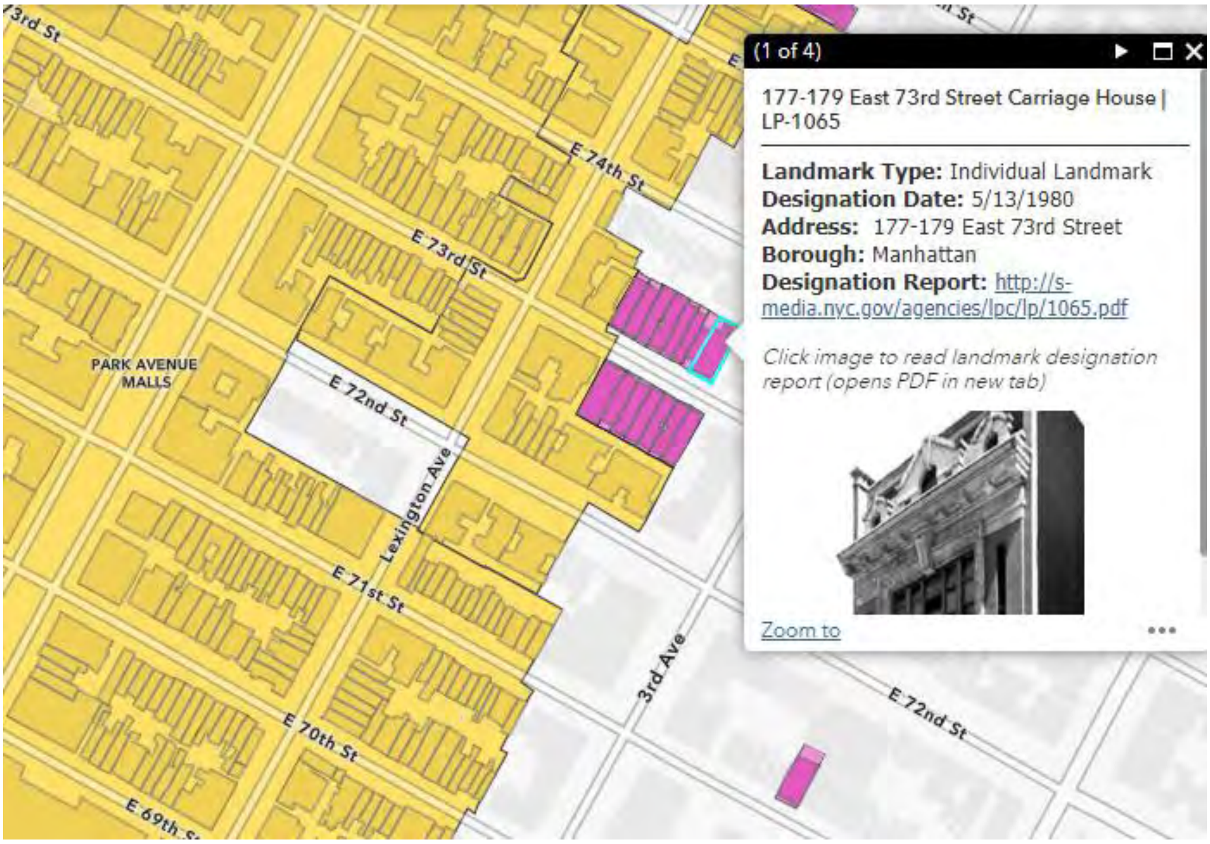

Figure 3: Landmark Preservation Commission Mapping of Manhattan Landmarks – Individual Landmark

4. Implementation of Monitoring

Typically, outside of Historic districts, the pre-construction documentation and monitoring requirements for adjacent structures is included on the support of excavation or underpinning design drawings. In NYC these plans must be signed and sealed by a design professional and submitted to the NYCDOB for review and approval. The monitors locations are included as a plan view of the general construction area, with an embedded table on the plan indicating the required monitoring frequency, action, and alert levels, etc.

Where the construction is within 90 feet (27.43 meter)—measured from the construction site property boundaries—of a mapped Historic district or Landmark structure, TPPN10/88 requires that a CMP be prepared, signed, and sealed by a design professional. Typically, a monitoring location plan is appended to the CMP, showing the excavation area and planned instrument locations.

Within Figure 4 is a "typical," project that reflects a NYC townhouse renovation where the lowest cellar level is being deepened to provide more headroom, and the rear yard is being excavated within the limits of the property line to extend the cellar level to allow for the construction of a pool room and other amenities. This cellar extension required excavation up to 25 feet (7.62 meter) deep in the rear yard with the use of both underpinning of an abutting building and a drilled soldier pile and timber lagging internally braced excavation system. This project is in a Historic district; therefore, a CMP was also prepared. Survey monitoring, tilt meter, liquid levels and vibration monitoring locations are shown on the plan. In this case an Automated Motorized Total Station (AMTS) was utilized to allow for data collection several times per day.

Figure 5 is another close quarter monitoring project. Although the building was not in a Historic district, it abutted several Landmark buildings. In this case, the existing building was going to be demolished, leaving the existing foundation walls to remain as partial support of excavation.

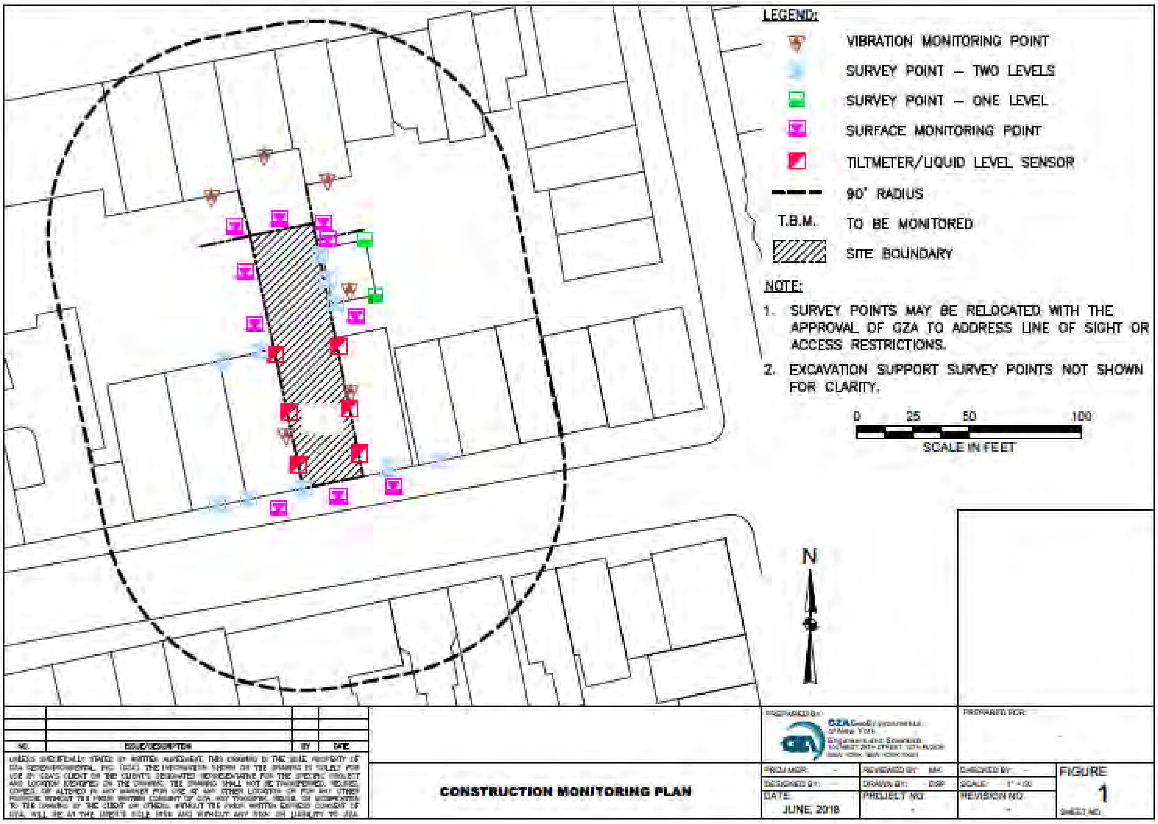

Figure 4: Typical NYC Townhouse Monitoring Project

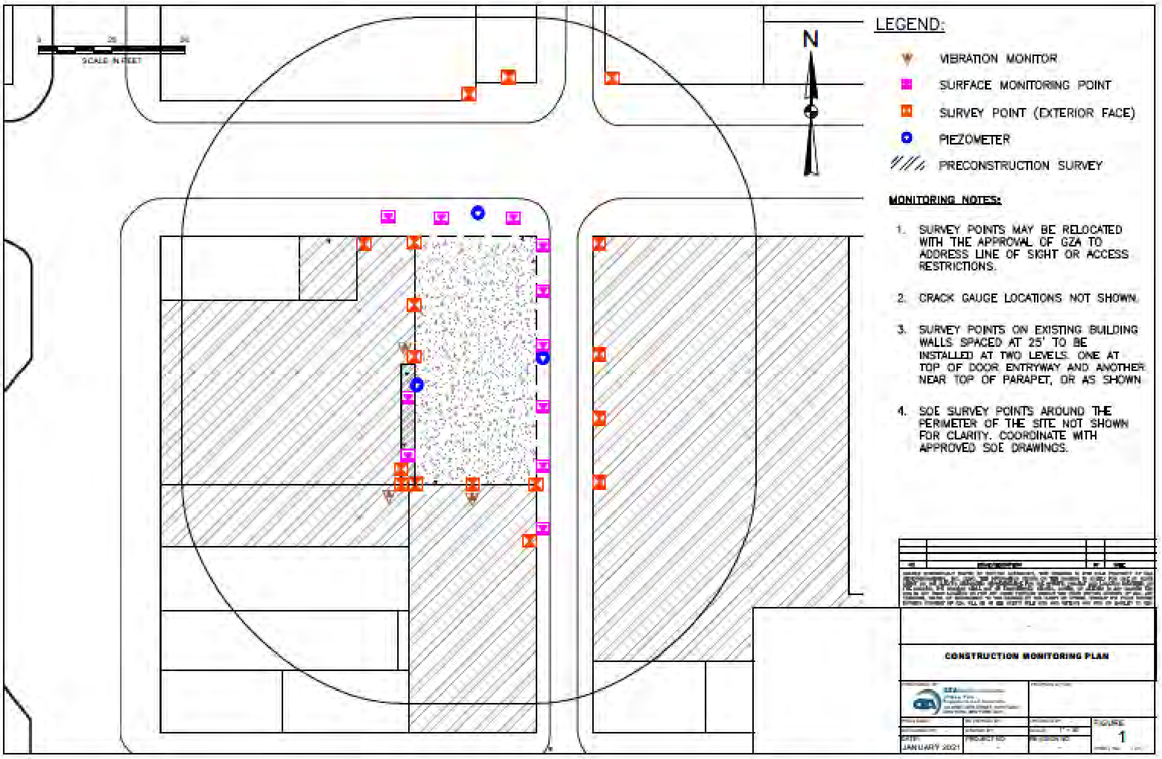

Figure 5: Non-Landmark Site Abutting Historic Structures (hatched) with Monitoring Locations

5. Typical Monitoring Programs

Pre-construction visual (photo) documentation is an integral portion of any urban monitoring program. Typically done on buildings and properties that directly abut the site, this documentation is completed before the start of excavation. The building's interior and exterior are typically observed from the readily accessible areas of the premises without the use of scaffolds, ladders, etc.

A description of each observed condition is provided, along with the location of the observation and its corresponding photograph. In general, the extent, length, area, range, or width of cracks or other deficiencies are estimated based on simple measurements and/or visual observation. In areas where no deficiencies were observed, a general description of the area is noted with a general overview photograph. A report which documents the observed conditions is then generated. It is worth noting that there is no written code standard for pre-construction visual documentation.

Although the NYC codes are prescriptive as to what general monitoring is required, there is no specificity as to the type of monitoring instruments utilized or the repeatability of such instruments. Most survey monitoring points are measured for movement in three directions (X, Y, Z) utilizing conventional survey monitoring equipment, such as "construction quality" total stations. This conventional survey monitoring is preferred on relatively small sites where the lines-of-sight are limited and when monitoring frequency is typically one or two times per week. Although this conventional monitoring has accuracy limitations (reflected by variation in weekly monitoring results), it will likely continue to be the most utilized monitoring method.

When the line-of-sight allows and monitoring frequencies are greater than one or two days per week, AMTS have been the preferred data collection method since introduced in NYC in approximately 2001. Given the smaller site sizes, AMTS use does have some limitations, including limited/non-optimal backsight locations, AMTS mounting locations, and access to adjacent property to install monitoring and backsight optical prisms, but those limitations are generally well worth the superior data quality, increased reading frequency, and ready availability of data via web-based data visualization programs.

When survey points are required inside narrow buildings, some monitoring firms have used a combination of liquid level systems to measure movement in the vertical direction with tiltmeters to give some measurement of lateral movement or inclination.

The measurement of vibrations has typically been done utilizing seismographs, installed within the lowest cellar levels of adjacent buildings or on adjacent exteriors where access is not obtained. Although it is understood that the standard vibration limits were intended to be measured within the soil directly abutting the adjacent buildings, the reality of the constricted urban locations in NYC has forced the placement within the lowest level of the adjacent building. In this situation, the geophone is typically bolted to the floor surface and communication enabled with cellular modems. Typically, the histogram combination setting is enabled for continuous data collection using an FFT filter and full wave form recorded if pre-set threshold values are exceeded.

Monitoring of cracks identified during pre-construction documentation has historically been undertaken by acrylic passive crack gages, recorded as access is available or by vibrating wire crack gages when more frequent or specific data collection is required.

Monitoring of groundwater levels is less likely to occur unless extensive dewatering is required, in which case groundwater levels are collected manually on a regular basis; alternatively, vibrating wire piezometers with self-contained water level data loggers are installed within conventional standpipe monitoring wells. Note that most monitoring wells are installed in the sidewalk or street, requiring dataloggers to be installed below grade. In NYC's dense urban environment, it's rare to have access to install wells or monitor the groundwater on more than one or two sides (corner lots) of a site, which can often limit the usefulness of the groundwater modelling.

Data collection management still varies by the firm that collects the instrumentation data and produces the report, from Excel sheets and Word documents sent via email to fully automated generation of reports using commercially available web-based data visualization programs. NYCBC requires hard copies of weekly monitoring reports be located on the construction site and available for NYCDOB inspector review. Reports are typically sent to the contractor to print in the field for storage on-site.

6. Instrumentation Costs

The cost of instrumentation, while not insignificant, is generally less than one percent of the overall project cost and is highly dependent on project duration and complex ability. Project duration is greatly influenced by the contractor's experience, materials, and craft labour availability. Duration may also be prolonged due to contract terms, problems that may arise due to legal agreements with abutting properties, and construction code violations which may cause temporary work stoppage by NYCDOB.

It is not uncommon for a total rehabilitation of a residential brownstone-constructed building located in a Historic district to have ongoing, below grade structural work that requires monitoring for one year or more. Assuming a simple instrumentation package of development of the CMP, two vibration monitoring locations, six passive crack gages, and 20 survey monitoring points requiring installation, twice weekly manual monitoring, and weekly reporting, cost in 2022 could easily exceed $130,000 USD.

7. Local Changes in Instrumentation Industry

Along with the introduction of more stringent protection and monitoring of adjacent structures promulgated in the 2014 NYCBC, the requirement that all temporary earth support systems be designed by a Professional Engineer (PE), submitted as part of the construction drawing package and reviewed prior to project approval drove the instrumentation work to design engineering firms. As discussed previously, prior to this time much of the design of temporary earth support systems on building projects was coordinated by the contractor who either performed this work with in-house engineering staff or subcontracted it to specialty firms, often located outside NYC. If the geotechnical engineer who performed the site investigation and prepared the geotechnical report was to undertake this design it was often only done conceptually to allow the project owner to level the contractor's pricing; when awarded, the contractor would ultimately take responsibility, often drastically revising the original design.

Concurrent with the 2014 NYCDOB changes, the NYC building market was responding to improved economic conditions and saw increased development of office towers, large scale residential buildings, and upscale, private residential development that was often located within or adjacent to the newly formed and/or expanded Historic districts. With these changes, the geotechnical engineering community began to slowly evolve, developing more temporary earth support system design and drawing sets in-house, designing instrumentation monitoring plans, and establishing appropriate vibration and displacement limits.

As these plans advanced through the NYCDOB review and approval process and projects began to go into construction, a small handful of the local geotechnical engineering firms that had been involved in instrumentation of infrastructure in the past began performing the installation and monitoring required on these non-infrastructure projects. It's interesting to note that prior to the mid-1990s instrumentation was not commonly utilized in NYC on private building projects as it recovered from the long-term economic impact of the 1970s recession and economic turmoil.

By the late 1990s a relatively large boom in tunnelling and infrastructure in and around NYC was changing the practices in instrumentation, largely influenced by engineering and construction firms from Europe. From the 1990s to 2014 there were only a few geotechnical engineering—and even fewer specialty instrumentation firms—practicing in and around NYC. The involvement of many of the firms had resulted from their registration as disadvantage businesses and federal set-aside requirements for contractors to contract with firms certified as such.

Since 2014, most active geotechnical firms consistently increased their instrumentation design, installation, and monitoring practices. There has also been an influx of new instrumentation specialty firms specializing in the

NYC building market. To demonstrate the influence of this additional work, the authors analysed the instrumentation-related work undertaken by their firms over a 10-year period (2012 to present), excluding (to the best of the authors' abilities) any instrumentation-related work not influenced by NYCBC (i.e., infrastructure projects), as shown in Figure 6. Reviewing this data from both firms, building-related instrumentation and monitoring projects increased up to 900% over this period.

As previously noted, this increase in work did not go unnoticed by other firms that had done little or no instrumentation in the past but now realized the potential of another market sector to add to their business model. Fortunately, given the prescriptive nature of the work required by NYCBC and the volume of work available, market pricing has been consistently profitable, allowing most firms to remain successful in this market, especially since privately funded building projects are excluded from federal disadvantaged business procurement requirements.

Not surprisingly, the increase in instrumentation also further strained NYC firms' need for qualified staff, given the overall strong economy, reduction in students enrolled in Civil Engineering programs in the USA, and more stringent emigration requirements for students from abroad.

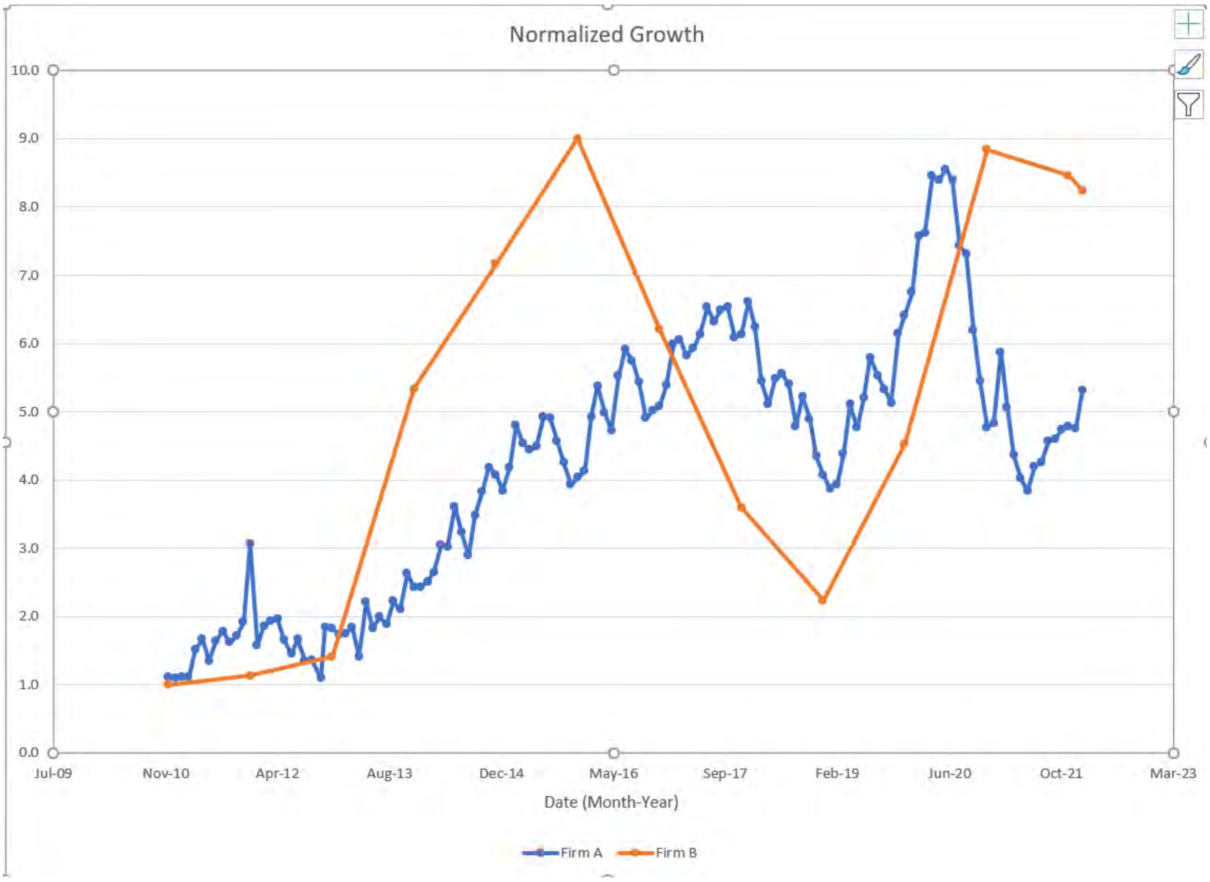

Figure 6: Normalized Plot of Increase in Building Instrumentation and Monitoring Growth

8. Conclusions

In the authors' experience, having a prescriptive building code that requires instrumentation for adjacent structures is not only extremely uncommon in the USA, but likely most of the world. Some would question if the prescriptive use of instrumentation has improved the practice or if it has increased the safety of people or structures. It is difficult to deny that the 2014 NYCBC changes have increased the profits of the geotechnical and other firms in the instrumentation field, as well as improving local instrumentation practices and increasing qualified staff capacity.

Like most construction related instrumentation, the collection of the instrumentation data and results have not, unfortunately, been internalized by the design community in a way that improves or provides value engineering of temporary support or foundation design elements. We surmise that there are two reasons for this. First the USA, especially NYC, is a litigious environment in which the legal community is quick to bring any damages, even minor ones, to court. The second reason is that the NYCBC, in addition to establishing prescriptive monitoring requirements, has also created prescriptive design standards which limit the potential for value engineering to contribute to design.

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References

Technical Policy and Procedure Notice 10/88 (TPPN 10/88) *Procedures for the Avoidance of Damage to Historic Structures Resulting from Adjacent Construction When Subject to Controlled Inspection by Section 27-724 and for Any Existing Structure Designated by the Commissioner.*

Melvin, E. & Andrew, C. (2014). *New York City Building Code: Avoidance of Damage to Historic Structures Resulting from Adjacent Construction*, Melvin Esrig and Andrew Ciancia, ASCE, New York, NY, 1981.