Monitoring Building Response to Adjacent Construction

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Figure 1: Large-scale excavation with adjacent existing buildings and hardscape.

New construction projects in congested urban settings commonly require demolition of an existing structure and deep excavation to accommodate several levels of below-grade parking or occupied space associated with the new building (*Figures 1* and *2*). The prediction and monitoring of building response to adjacent construction activities is necessary to minimize building damage resulting from subsurface movement and ground-borne construction vibrations.

Potential Impacts from Construction Activities

The most common construction activities associated with urban construction projects and their potential impact on adjacent buildings are described below.

Excavation Support Systems

Deep excavations for urban construction require installation of temporary earth supports, such as cantilevered systems (sheet piles or soldier piles and timber lagging), anchored systems using tiebacks, or strutted systems (cross-lot braces, corner braces, or raked braces).

Inward deflection of earth-retaining systems during excavation results in lateral movement of existing soils outside the excavation, as well as vertical settlement of building components supported on the shifting soil. The amount of vertical settlement is dependent on the flexibility of the earth-retaining system, depth of excavation, type of soil, and distance away from the excavation. The variation of settlement with distance from the excavation can cause differential settlement of the building.

Underpinning

Foundations of existing buildings are frequently underpinned to deeper bearing strata to accommodate adjacent new construction. A common method is concrete pit underpinning, which typically involves sequential and phased installation of simple concrete foundation elements directly beneath the existing foundation that needs to be extended downwards. Some vertical settlement, potentially on the order of ¼ inch to ½ inch, should be expected as a result of underpinning procedures, which include excavation and transfer of loads to the typically continuous underpinning components. Larger vertical movement can occur when widely-spaced intermittent underpinning piers or intermittent underpinning piers with relatively flexible interpier beams are used. Additional vertical movement can also occur from settlement of the bearing strata beneath the underpinning piers. This typically happens if the size or depth of the new underpinning elements is not sufficient.

Often underpinning piers are also part of the earth-retaining system. As with other excavation support systems, their lateral movement can result in vertical settlement of retained soils.

Dewatering Operations

Deep excavations often require dewatering. Dewatering has the potential to cause ground settlement, settlement of pile foundations due to drawdown (negative skin friction), or rotting of untreated wood pile foundation systems.

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Figure 2: Adjacent buildings and retained facade underpinned to permit excavation.

Removing water from weaker, compressible soil strata, such as soft clay, peat, and silt, effectively increases the stress on the soil, which can cause consolidation. Depending on the extent of compressible soils and the profile of the water-elevation drawdown, settlement can either be uniform or differential over the building footprint. On pile-supported buildings, consolidation of soil around piles can create negative friction resulting in a downward force on the piles and subsequent settlement.

When sections of previously immersed, untreated wood piles become exposed to air, conditions such as moisture and abundant oxygen, necessary for fungal growth, are created and initiate an accelerated decay process. The rate of deterioration of piles is highly sensitive to even minor variations in the environment around the piles: wood species, soil chemistry and makeup, etc. Consequently, the duration of exposure necessary to significantly impair the structural integrity of timber piles is unpredictable, but is usually longer than the length of most temporary construction-related dewatering operations.

Ground-borne Vibrations

Ground-borne vibrations associated with construction can cause architectural damage to building components, such as interior finishes or exterior facades, structural damage, and settlement or consolidation of loose fill supporting structures and utility services. Deep foundation installation is a common activity with potentially damaging vibrations associated with driving, vibratory, or drilling (*Figure 3*) operations. In addition to the physical effects on structures, ground-borne vibrations can be alarming and disruptive to building occupants and can disrupt vibration sensitive equipment. Different types of construction equipment cause different types and levels of vibration; selection of the appropriate construction approach is important when it comes to vibration control and mitigation.

Demolition Activities

Although typically not anticipated to affect adjacent buildings when done carefully and responsibly, demolition activities can also result in damage. Additionally, demolition activities can alter existing support systems for remaining adjacent buildings. This is often the case when a building on one side of the party wall is demolished, rendering an inadequate or compromised lateral bracing support for the remaining party wall. Such situations require immediate (temporary) stabilization measures (*Figure 4, page 18*).

Figure 3: Close-in construction operations.

Project Criteria

The design professional should prepare performance-based contract requirements in consideration of anticipated responses of adjacent buildings during construction. An example is a performance-based specification for temporary earth support that outlines permitted systems, performance limitations on movement, and monitoring strategies. This approach allows the contractor competitive freedom to determine how to accomplish the construction, but maintains controls established by the design professional, with the specific intent to minimize damage to adjacent buildings.

This approach requires that design professionals survey the condition of adjacent properties to understand their present condition and fragility, establish acceptable response limits, conduct soil-structure analyses of various earth support systems and develop limits on their respective movements (to be included in the performance-based specification), and develop a monitoring strategy.

Design professionals establish thresholds and limiting criteria for the monitoring program for each aspect of building response (settlement, translation, rotation, and/or vibration). Thresholds and limiting criteria are safeguards established for each adjacent structure based on age and type of construction, condition of the building, and perceived sensitivity of the building to movements. In establishing thresholds and limiting criteria for vibrations, design professionals need to consider that human perception of vibration occurs at levels much less than needed for damage, and that adjacent buildings might house tenants working with vibration-sensitive equipment. When a criterion of building response is reached or exceeded, the contractor will be required to implement a mitigation program, which may include alteration of the excavation/construction approach, intensified monitoring to allow for

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a timely response, or, in extreme cases, stabilization and shoring of already damaged building components. A well-defined set of criteria and an up-front agreement between all involved parties goes a long way towards avoiding construction delays and damage claims.

Quite often, design professionals are not retained for these services. In such cases, responsibility to monitor and protect adjacent structures is allocated to the contractor. Under this scenario, the contractor and their specialty structural engineer need to establish acceptable responses of adjacent properties, design the earth support system accordingly, and develop a monitoring strategy. A loosely-defined performance-based specification for excavation support using this approach might contain language similar to "design, furnish, install, monitor, and maintain excavation support capable of resisting soil pressure, hydrostatic pressure, and superimposed loads without damaging existing buildings, pavements, and other improvements adjacent to excavation." This approach does not necessarily put the best interests of the adjacent building at the forefront of the decision-making process and can become the source of heated debates when: adjacent structures get damaged (*Figure 5*), when additional efforts are required to mitigate damage, or when parties have differing opinions on what constitutes damage. Unfortunately, this scenario is too often seen in some of the densest urban environments.

Figure 4: Stabilization of party wall following demolition.

Monitoring Building Response

Monitoring building response during construction is intended to provide information on movement and pertinent structural and other changes to adjacent structures, as well as information on performance of the construction technique. The monitoring program can be divided into three parts: pre-construction and post-construction surveys, building-performance monitoring, and construction diagnostic monitoring.

Pre-construction and Post-construction Surveys

A pre-construction survey is used to document existing conditions of adjacent properties prior to the start of any construction activity, including demolition. The survey can include a combination of hand sketches with narratives, still photographs with annotation of interior and exterior conditions, and video (preferably with narratives) of interior and exterior conditions. The survey should be conducted by an experienced individual who will conduct a diligent and organized survey. At the conclusion of the pre-construction survey, a representative from the project team and a representative from the firm that conducted the survey should meet with the adjacent property owner or property manager to walk them through the survey report and reach agreement with the representations contained in the survey report.

The design professional or specialty engineer needs to determine the appropriate time to require a post-construction survey. The decision will need to consider anticipated durations of construction events. Potential times to be considered are when excavation reaches final subgrade, when new construction reaches grade, or at project completion. Depending on existing conditions of certain adjacent structures, the design professional may require an interim survey when excavation reaches final subgrade, and then require a final survey at project completion. The pre-construction survey should form the basis for the post-construction survey. Similar to the pre-construction period, a meeting should occur with the adjacent owner or property manager.

Building-performance Monitoring

Building-performance monitoring records responses of the structure (settlement, translation, rotation, and vibration) to construction activities over a period of time, and frequently enables timely response to mitigate damage. The design professional or specialty engineer establishes requirements for the monitoring strategy based on responses of adjacent structures. Requirements should identify type of instrumentation, specific locations for instrumentation on adjacent buildings, frequency of instrumentation recording, method of reporting recorded data, and responsibilities of specific parties for evaluating collected data (including mitigation program when pre-established limits are reached or exceeded).

The workhorse of a monitoring program is a total station. A total station is a versatile piece of equipment that allows high-accuracy, long-distance, and angular measurements, by producing 3D positioning records of monitoring points. Most equipment use reflecting prisms as targets mounted to a building. Some have reflectorless capabilities that use a visible red laser to site a feature of the structure. A significant amount of data can be electronically collected in a relatively short time. Also, a macro can be created in a template spreadsheet to extract collected data and process information automatically into tabular form and trend-line plots.

Data captured by the 3D positioning system is primarily used to evaluate vertical movement for settlement and horizontal extension (in-plane translation). Vertical movement can also be used to evaluate angular distortion, which is the differential settlement divided by the horizontal distance between two monitored points. Horizontal extension is important because it is used in conjunction with angular distortion to assess potential for structural damage.

Captured data from a total station also contains out-of-plane translation, which can be used to evaluate out-of-plane rotation or tilt. However, when evaluating movement data, design professionals should consider the impact of environmental factors on building components that are being recorded. The trend plot created from discrete measurements using a total station may show scatter from thermal movements that can cloud the trend of actual construction-induced movements. Use of a tiltmeter or inclinometer instead results in more meaningful information to evaluate out-of-plane rotation or tilt. These instruments can be mounted on exterior walls and linked with a data logger to capture continuous measurements that include time and temperature. This type of monitoring strategy will also capture daily cyclic movements of walls subjected to environmental conditions, as well as any construction-induced movements.

Ground-borne vibrations are best monitored using seismographs with multiple triaxial geophones mounted on the structure. The flexibility of multiple geophones allows a design professional to capture source vibrations at the foundation level, and understand how those source vibrations attenuate or amplify through the structure. This feature is important because most empirical industry standards are based on vibration levels at the structure base, but occupant discomfort and disruption of

Figure 5: Damage resulting from adjacent construction.

tenant operations occurs on elevated floors. In addition, measurement of vibration at higher levels can be used to evaluate the likelihood of alleged damage. Seismographs can be set to trigger mode (recording only activates when a base magnitude is reached) or to a continuous mode. Continuous mode provides more information, but also requires more storage capacity.

Both a data logger for the tiltmeter/inclinometer and a seismograph can be connected with phone or internet service to allow remote access to review and download data or modify settings.

Although "low tech" compared to other instrumentation described, crack gauges are a critical part of a monitoring program. These simple devices provide quick tell-tale indications of building response to those in charge of monitoring building behavior. Typically, crack gauges are installed at existing cracks or at joints between different building components where movement can be expected.

Construction Diagnostic Monitoring

Construction diagnostic monitoring systems record behavior or performance of particular construction-related components such as underpinning piers and earth support systems. Diagnostic monitoring information is compared with anticipated behavior predicted by analysis to evaluate performance and provide information regarding potential problems. In addition, monitoring of these components provides information that can be used to understand adjacent building responses. Similar to building-performance monitoring, construction diagnostic monitoring typically has associated threshold and limiting criteria, and uses similar instrumentation (total station, tiltmeter, and inclinometer).

Reporting and Evaluation of Monitoring Data

A consultant retained to execute the monitoring program should prepare summary reports of collected data for distribution to the design professional, contractor, contractor's specialty engineer, and other designees associated with the project. The need for promptness in preparation and distribution of monitoring reports cannot be overemphasized. The contract documents should explicitly state time requirements for distribution, such as within 24 hours of collection of data.

Contract documents need to establish which party has responsibility to evaluate collected monitoring data, determine a cause-and-effect basis, and evaluate appropriate actions to eliminate or slow any movement trends. Without clear ownership, the process can be ineffective.

Conclusions

Well conceived and executed construction monitoring provides vital information regarding response of buildings adjacent to construction, as well as performance due to construction techniques. Monitoring programs serve as a safeguard against harmful events. Although development and implementation of a well-defined monitoring program may seem expensive at the outset of the project, lack of one can result in damage and claims that will likely far exceed program cost. Owners, developers, design professionals, and contractors need to recognize the importance of a monitoring program in protecting all parties involved in a construction project.▪

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