Geotechnical Instrumentation for Deep Excavations in Boston

The use of geotechnical instrumentation to monitor the construction of deep excavations provides a way to minimize potentially damaging movements.

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During the past 25 years of major development in downtown Boston, several deep excavations have been constructed for below-grade parking and other uses. Geotechnical instrumentation programs have often played a key role in contributing to the success of these projects. The documented performance data from many of these past programs can now be utilized effectively in connection with the planning, design and construction of future deep excavations, especially for Boston's extensive Central Artery/Tunnel project.

The magnitude and potential impact of the movements associated with any deep excavation are dependent on both engineering design and construction procedures. Typically, a main goal is to limit detrimental movements of adjacent facilities. Dependable geotechnical instrumentation is necessary to measure the movements of adjacent streets, buildings or buried structures. Competent engineering interpretation and evaluation of the performance data are essential for appropriate construction control and modification, when required.

Geotechnical Concerns Associated With Deep Excavations

The engineering of deep excavations involves a process of several interrelated steps that include:

1. Characterizing and evaluating subsurface conditions
2. Identifying adjacent structures and utilities that may be impacted by the excavation
3. Determining predicted and permissible movements resulting from the excavation
4. Selecting an appropriate excavation

TABLE 1
Concerns Related to Deep Excavation Activities

	Construction Activity	Concern
Excavation Support System Wall Installation	Pre-excavation of existing foundations and/or obstructions	Soil disturbance/loss of strength
	Pile driving	Vibrations at adjacent structures Soil densification & settlement
	Drilled pile/diaphragm wall installation	Loss of ground/collapse of soils
Excavation & Bracing Sequence	Excavation	Movement of adjacent ground
	Overexcavation	Additional loading of excavation support system (additional movements of adjacent ground)
		Reduction in passive soil support of wall toe
	Excavation in soft clay	Basal heave (bottom instability)
	Bracing installation	Time duration between excavation & bracing installation
		Proper bracing details (spacing, shimming, stiffeners & prestressing)
		Reduced passive resistance/stability of earth berm
		Loss of ground during tieback installation
		Poor tieback performance
		Insufficient raker action from kicker blocks or deep foundations
	Equipment or material surcharge loads	Additional loading of excavation support system (additional movements of adjacent ground)
	Bracing removal & backfilling	Improper sequence leading to additional loading of excavation support system (additional movements of adjacent ground)
Groundwater Control	Exposed silty/sandy soil at excavation face	Loss of ground (piping)
	Inappropriate dewatering program or excavation support system	Excess hydrostatic pressures at base of excavation
		Lowering groundwater or piezometric levels outside excavation limits
Other Construction Activities	Installation of deep foundations within the excavation	Soil disturbance/loss of passive soil resistance adjacent to excavation support system wall

support system and excavation/bracing sequence

5. Monitoring excavation performance
6. Adjusting the design/construction as required

During the design phase, uncertainties associated with variable subsurface conditions and the construction process should be identified. Table 1 presents a partial listing of the concerns associated with specific deep excavation construction activities.

Due to the difficulties in predicting excavation-related movements, the Observational Method as outlined by Peck[1] is usually incorporated into the design and construction of deep excavations. Instrumentation plays an integral role in the success of the Observational Method. In many instances, the Observational Method can reduce construction costs and time by helping to avoid unnecessary conservatism in design, and by helping to mitigate field problems.

Purpose & Benefits of Instrumentation

When implementing the Observational Method for deep excavations, the use of an appropriate instrumentation program is essential. Some of the more significant benefits, modified from Dunnicliff,[2] include the following:

Safety. Most deep excavations in urban areas are instrumented to help protect adjacent streets, utilities and structures, as well as workers within the site limits. Instrumentation can serve as an early warning system to identify a potentially unsafe condition prior to its occurrence.

Reduce Construction Costs. In association with the Observational Method, instrumentation can allow for a less conservative excavation design, which can ultimately result in a savings of time, labor and materials required for constructing the excavation, the support system and the primary structure. In the case of favorable performance, instrumentation data may also justify a relaxation in the specified excavation/bracing scheme during construction, producing additional savings.

Additional Construction Control. Control of the excavation process can result in utilizing instrumentation to "calibrate" various construction activities. This method allows for an iterative design approach. Initial construction or test section performance of the excavation system is first measured and evaluated. Subsequent phases of construction are then conducted based on the measured initial behavior with appropriate design adjustments as necessary.

Instrumentation also permits qualitative construction control. Predetermined movement criteria of the excavation support system may be established in the contract documents, and may direct the contractor to perform mitigative measures if the criteria are exceeded. In some instances, criteria may be used to assign liability for damage to adjacent properties.

Documentation. Instrumentation data serve to document the excavation progress and performance. The data can document the relationship between construction activities and alleged damage to structures adjacent to the excavation. This information might help to avoid litigation or, in the event of litigation, to help deny a false claim or substantiate a true claim by surrounding property owners. The data can also be valuable in resolving potential claims by the contractor, owner or other involved parties.

Public Relations. The implementation of an instrumentation program can reassure outside interested parties (adjacent property owners, special interest groups, government agencies, *etc.*) that their interests are being accommodated. In situations where community or political opposition exist, instrumentation can demonstrate a commitment to enhance project safety and a preventative method to minimize potential construction related problems. Both of these factors can facilitate obtaining project approvals.

Advance State-of-the-Practice. The results of instrumentation monitoring can provide significant insight into the behavior of deep excavations. The experience and understanding that is gained through the availability of those results can be applied to similar projects in order to avoid construction procedures that were unsuccessful or had unfavorable impacts. Likewise, procedures that resulted in a savings in costs or schedule, or favorable performance could be repeated. Instrumentation monitoring also allows the use of innovative excavation support systems that otherwise may not be attempted. Using instrumentation, the safety and performance of a new approach can be monitored and evaluated.

Methods & Procedures for Monitoring Deep Excavations

Several steps are involved in a deep excavation monitoring program. These steps typically include:

TABLE 2
Instrumentation for Monitoring Deep Excavations

Instrumentation Type	Remarks
Surface Reference Points (Survey)	Points established on streets, sidewalks & utility manholes to measure settlement/heave
Deep Reference Points	Typically consist of subsurface settlement points & extensometers; used to measure settlement/heave below ground surface
Building Reference Points (Survey)	Points or features on buildings to measure settlement/heave
Off-Set Survey	Measures horizontal movements of streets, utilities, buildings & excavation support system
Observation Wells	Determines groundwater levels; generally used to measure groundwater level in cohesionless fill soils (Boston area)
Piezometers	Measures groundwater pressure at a particular subsurface location
Inclinometers	Provides a profile of subsurface horizontal movements; typically used on excavation support systems & behind the system within adjacent soil
Strain Gages/Load Cells	Measures load in the excavation support system & associated bracing (struts & tiebacks)
Vibration Monitoring	Pile driving, demolition, diaphragm wall installation (chiseling)

Establish Goals. In general terms, the goal of an instrumentation program is to develop and install instrumentation that is responsive to the specific needs of the project.

Instrumentation Program Design. Table 2 outlines the geotechnical instrumentation typically used for monitoring deep excavations. Figure 1 graphically presents one idealized layout of instruments, showing their possible deployment. Selecting the type and location of instruments depends on the specific project details of the excavation support system, subsurface conditions, excavation depth and configuration, proximity and type of adjacent facilities, and other project-specific concerns.

Data Collection. Initial instrument readings are taken prior to construction so that a baseline of data is obtained that is independent of any ongoing construction activities. The schedule of instrument monitoring during construction is usually flexible and generally dictated by construction activities. Monitoring schedules may be adjusted as information is collected, based on data trends and agreement with predicted behavior.

Data Presentation. Most data should be plotted against time, with relevant construction activities noted on a time line. Data presentation should allow for an objective evaluation of the construction status. Figure 2 presents examples of time plots of subsurface reference point and piezometer data. Time plots aid in the interpretation of data trends (increasing or decreasing) and indicate a range of instrument repeatability. In addition to time plots, plan views indicating area or project-wide variations in instrument data can be useful in identifying the causes of observed performance and potential areas of concern.

Data Interpretation. The interpretation of instrument data and the potential impacts on construction procedures must be per-

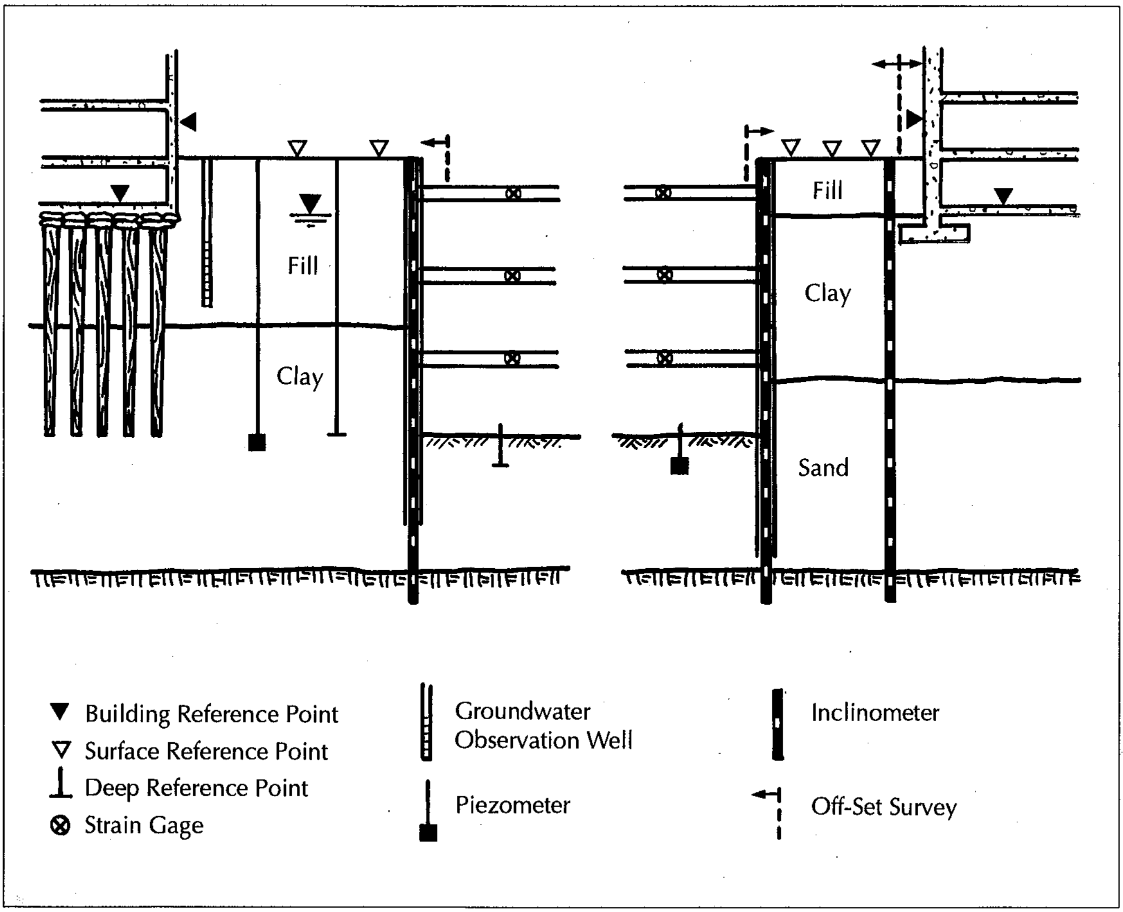

FIGURE 1. Idealized instrumentation layout for deep excavations.

formed by personnel experienced in the evaluation and construction of deep excavations. It is important that all persons involved in the interpretation process consider all available monitoring data, and possess a detailed knowledge of the design assumptions and construction activities. Instrument precision must also be understood in order to distinguish random data fluctuations from actual data trends.

Communication Procedures. The effective implementation of an instrumentation program requires that channels of communication and assignment of responsibility be clearly established. The results of instrumentation monitoring, and the implications of the data acquired, should be regularly reviewed and discussed among members of the design and construction team. All parties involved (contractors, engineers and owners) should be aware of the implications of data interpretation, since such interpretation will have a direct bearing on the decisions that may be reached during construction that may alter the construction process.

Often, instrumentation data are made available to adjacent property owners and city building officials. The information is typically provided without significant interpretation. For their protection, these owners may obtain an independent evaluation of the data in order to assess the potential impacts to their property.

Instrumentation of Deep Excavations in Boston

The history of deep excavations in Boston dates back to at least the 1880s with the cut-and-cover construction of the Dorchester Bay Sewage Tunnel.[3] However, the history of instrumented

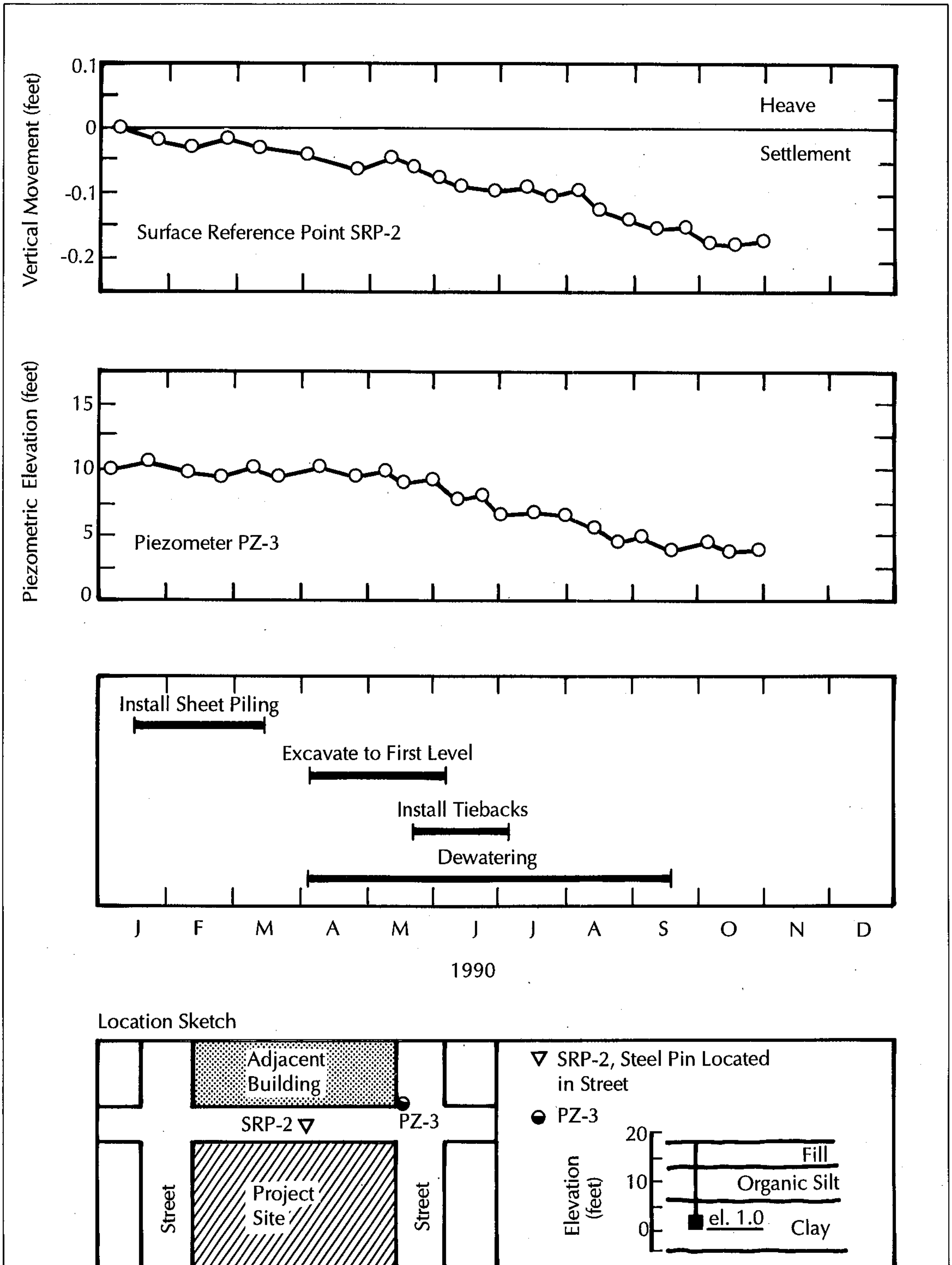

FIGURE 2. Idealized presentation of instrumentation data.

deep excavations in Boston is more difficult to document. Casagrande indicates that the monitoring of surface and building reference points outside the excavation limits, as well as off-set surveys of the excavation support system, were conducted during foundation construction of two Back Bay building projects during the late 1930s and mid-1940s.[4,5] Aldrich and Lambrechts indicate that groundwater levels in the fill were also monitored during construction of these excavations.[6]

In 1970, Lambe, Wolfskill and Wong prepared one of the earliest publications that extensively documented the performance of a deep excavation in Boston.[7] They presented data collected from piezometers, inclinometers, strain gages and load cells in connection with the extension of the Massachusetts Bay Transportation Authority (MBTA) Orange Line. This publication represented a continuation of studies that were initially performed by Lambe during the instrumentation of excavations in the mid-1960s for buildings constructed on the Massachusetts Institute of Technology campus.

Starting in the early 1970s, several case studies have been published regarding the performance of instrumented deep excavations in Boston. During the past 25 years, instrumentation of excavations in congested downtown areas of the city has become standard practice. The dramatic increase in instrumentation use during this period is attributable to several factors, including:

Electronic Advances. With the development of computers, strain gages, inclinometers, data acquisition systems, and related technologies, instrument data could be more quickly read, reduced and evaluated.

Construction Technique Advances. The introduction of reinforced concrete diaphragm walls, tiebacks and other excavation support technologies required instrumentation in order to evaluate performance, since local experience with these construction methods was limited or nonexistent.

Underground Space Development. Due to the significant increase in below grade construction for parking garages, transit tunnels and utilities, instrumentation was required to help limit adverse effects on adjacent facilities.

Increased Litigation. A societal tendency toward increased litigation, in combination with advances in the ability to measure excavation related movements, has led to increased claims by adjacent property owners. The quantification of detrimental movements can be used to assess blame to parties involved.

Local Subsurface Conditions. The complex, variable and often unfavorable subsurface soil and groundwater conditions in the Boston area complicate underground construction and make performance predictions difficult. An instrumentation program provides a way to increase the confidence of owners, engineers and contractors that such deep excavation can be successfully completed, even under difficult subsurface conditions.

Examples of instrumented excavations conducted in Boston over the last 25 years are presented chronologically in Table 3. The projects listed were limited to excavations of at least three levels deep ($\pm$ 30 feet). The location of the excavations listed in Table 3 are presented in Figure 3.

Boston Case Histories

The following studies illustrate the use and impact of instrumentation on several recent deep excavations in Boston.

International Place (1985). Both the Phase I and II excavations of the International Place projects were supported using a soldier pile and lagging system that was externally braced with tiebacks.[14] A typical cross-section of the excavation support system for the Phase I construction is shown in Figure 4. During geotechnical design for the Phase I excavation, an apparent earth pressure diagram (also shown in Figure 4) was recommended by the owner's geotechnical engineer for the temporary excavation condition.

During the excavation-submittal process, the contractor designed the excavation support system assuming an apparent earth pressure diagram with the same stress distribution shape, but of lower magnitude (20H, where H

TABLE 3
Examples of Instrumented Deep Excavations in Boston

Project Number (see Figure 3)	Project/Location	Start of Construction	Depth of Excavation (feet)	Earth Support System*	Bracing Type**	Instrumentation Used***	Reference
1	MBTA Subway Extension/Accolon Way	1967	40-60	SSP	Struts	SRP, BRP, PZ, INCL, SG, LC	7
2	One Beacon St. Office Building	1969	35-55	SP&L	Tiebacks	SRP, BRP, OSS, INCL, SG, LC	8
3	MBTA Subway Extension/South Cove	1969	60-80	RCDW, SSP	Struts	SRP, DRP, BRP, PZ, INCL, SG	9
4	Ashburton Place Garage	1971	30-50	SP&L	Tiebacks	BRP, OSS, SG	10
5	Federal Reserve Bank Building/Atlantic Ave.	1973	20-45	SP&L	Tiebacks	SRP, OSS, INCL, LC	11
6	60 State Street Office Building	1976	35-50	RCDW	Tiebacks	SRP, DRP, BRP, OSS, OW, PZ, INCL, LC	12,13
7	The Devonshire Bldg./ One Devonshire Place	1980	30-40	SP&L	Rakers	BRP, OSS	14
8	State Transportation Building/Park Plaza	1981	30-35	RCDW	Tiebacks, ICB	SRP, BRP, OSS, OW, PZ, INCL, SG, LC	14
9	Southwest Corridor Project/Blackwood to Yarmouth Sts.	1981	30-40	RCDW, SSP	Struts	SRP, BRP, OSS, OW	6,14
10	Lafayette Place Garage/Washington St.	1982	30-35	SP&L	Tiebacks, Rakers	PZ, INCL, SG, BRO, OSS	14
11	International Place (Phase I)/ High St.	1985	50-55	SP&L	Tiebacks	SRP, BRP, OSS, OW, PZ, INCL	14
12	Rowes Wharf/Atlantic Ave.	1985	55	RCDW	Top/Down Construction	INCL	15,16
13	MBTA Station Platform Lengthening/Summer St.	1985	40-45	RCDW	Struts	DRP, BRP, OSS, PZ, INCL, SG	14
14	150 Federal St. Office Building	1986	35-40	SP&L	Tiebacks, Rakers	SRP, BRP, OSS, OW, INCL	17
15	500 Boylston St. Office Building	1986	35-40	RCDW, SSP	Tiebacks, Rakers	SRP, DRP, BRP, OSS, OW, INCL	14
16	Heritage-on-the-Garden/ Boylston St.	1986	30-45	SSP	Tiebacks, Rakers, ICB	SRP, BRP, OSS, OW, PZ, INCL	14
17	75 State Street Office Building	1986	65	RCDW	Top/Down Construction	SRP, BRP, OW, PZ, INCL	16
18	125 Summer Street Office Building	1987	45-50	RCDW	Top/Down Construction	SRP, BRP, OW, PZ, INCL	14,18
19	745 Atlantic Avenue Office Building	1987	30-35	SSP	Tiebacks, ICB	SRP, BRP, OSS, OW, INCL, SG	14
20	125 High Street Office Building	1987	55-60	SP&L	Tiebacks, Rakers	SRP, BRP, OSS, OW, PZ, INCL, SG	14
21	Flagship Wharf/ Charlestown Navy Yard	1988	50	RCDW	Struts, ICB	BRP, INCL, SG	19
22	Post Office Square Garage	1989	75	RCDW	Top/Down Construction	SRP, BRP, OW, PZ, INCL	20,21
23	International Place (Phase II)/ High St.	1989	50-55	SP&L	Tiebacks	SRP, BRP, OSS, OW, PZ, INCL	14
24	222 Berkeley Street Office Building	1989	35	SSP	Tiebacks, Struts	SRP, DRP, BRP, OSS, OW, INCL	14

Notes: *Excavation Support Systems: SP&L = Soldier Pile & Lagging; RCDW = Reinforced Concrete Diaphragm Wall; SSP = Steel Sheet Piling.
**Bracing Type: ICB = Internal Corner Bracing.
***Instrumentation Used: SRP = Surface Reference Point; DRP = Deep Reference Point; BRP = Building Reference Point; OSS = Off-Set Survey; OW = Observation Well; PZ = Piezometer; INCL = Inclinometer; SG = Strain Gage; LC = Load Cell.

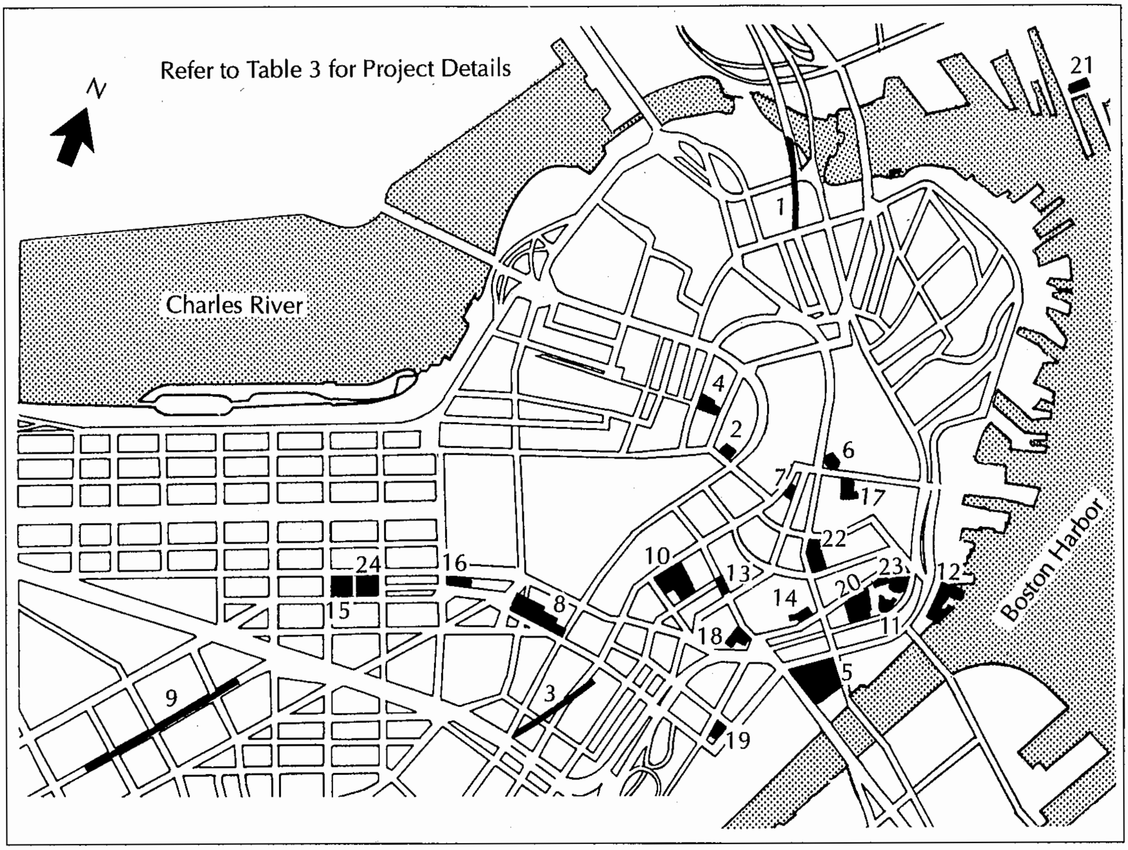

FIGURE 3. Location of instrumented excavations in Boston.

equals the height or depth of the excavation). The contractor believed that a reduced earth pressure was warranted due to the dense nature of the site glacial soils. Additional laboratory strength testing of the soils was performed by the contractor to support that contention. The reduction of the earth pressure diagram would result in a cost savings for the materials required to construct the support system.

Since the 50- to 55-foot deep excavation was to be well instrumented, the project geotechnical engineer agreed to proceed with the design of the excavation using the contractor's proposed earth pressure diagram. Performance of the system during construction indicated inclinometer displacements of less than ⅜ inch as shown in Figure 4. Ground surface settlements of adjacent streets surrounding the site were typically less than ⅜ inch. Due to the favorable performance of the Phase I excavation system, as measured by the instrumentation program, the reduced temporary earth pressure diagram was recommended for the Phase II construction that began four years later.

500 Boylston Street (1986). The 500 Boylston Street project involved a 35- to 40-foot deep excavation in difficult soils consisting of miscellaneous fill, organic silt and a thick stratum of Boston Blue Clay.[14] The project was constructed in a highly visible and politically sensitive urban area, which included the adjacent historic Trinity Church as shown in Figure 5. Fifteen years previously, the nearby John Hancock Tower excavation, which was similar in depth and size, resulted in significant excavation-related movements that ultimately led to litigation by the Trinity Church.

Primary construction goals included limiting ground and building movements outside the site and maintaining existing groundwater levels. To achieve these goals, the construction contract documents provided specific excavation design and performance criteria such as the spacing of bracing levels, excavation se-

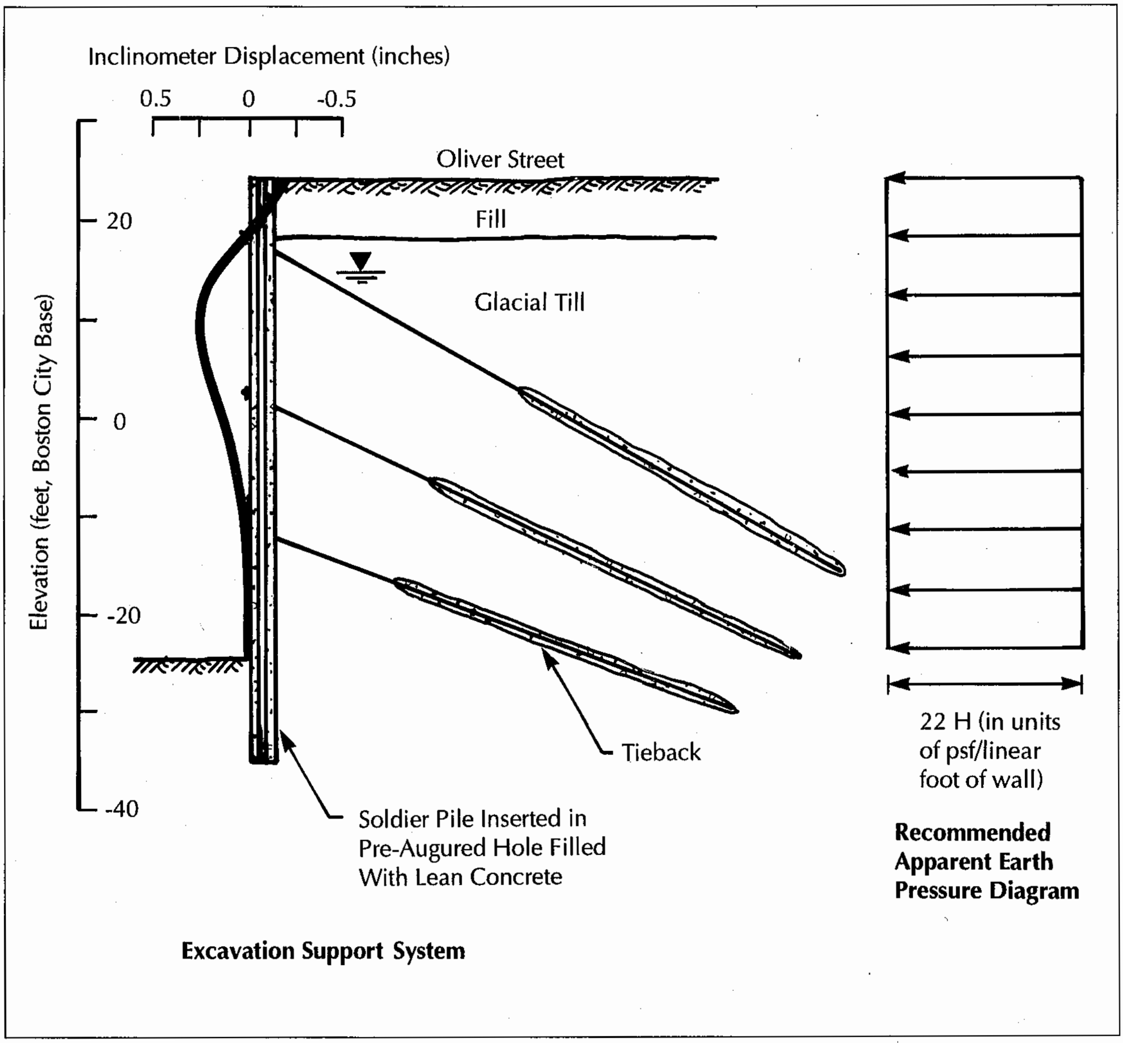

FIGURE 4. International Place (Phase I) excavation support details.

quencing and geometry, and limits on support system wall movements and groundwater drawdown. The use of a reinforced concrete diaphragm wall was specified.

To address both construction and political concerns associated with the excavation, a detailed instrumentation and monitoring program was required before the project was approved. The instrumentation program provided data to assess excavation support system wall movements and groundwater level changes against the contractually established performance limits. Prompt data collection, interpretation and reporting were essential to maintain good public relations with adjacent property owners and government agencies.

The instrumentation program consisted of numerous surface reference points, building reference points, deep reference points to measure heave, observation wells and, most importantly, inclinometers. Figure 6 presents the location of most of the instruments used.

During construction, movements of the excavation support system approached and, in some cases, exceeded the specification criteria. The instrumentation played a vital role in the project's success by aiding the development of appropriate mitigating actions, and by demonstrating to all interested parties that the movements were not adversely impacting adjacent facilities.

Heritage-on-the-Garden (1986). The excava-

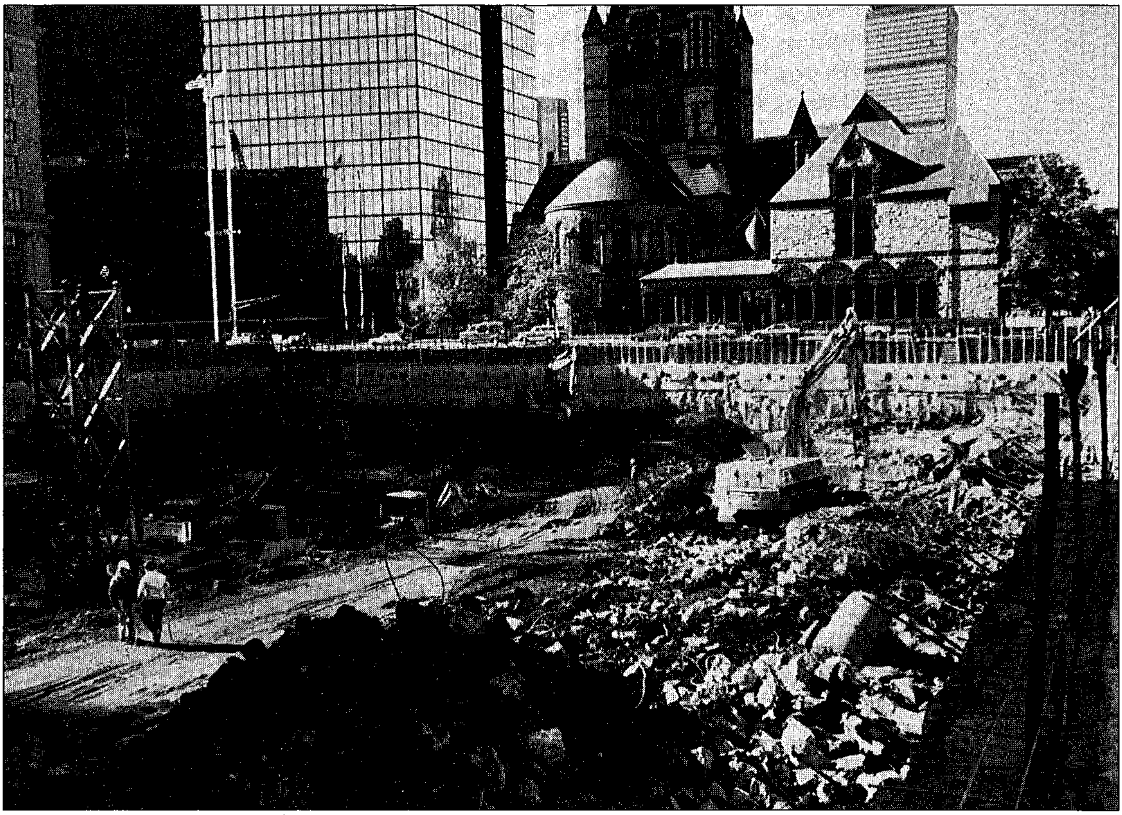

FIGURE 5. A view of the 500 Boylston Street excavation with the adjacent Trinity Church.

tion support system for the Heritage-on-the-Garden project consisted of interlocking steel sheet piling supported by internal bracing and tiebacks.[14] An existing MBTA Green Line tunnel along Boylston Street precluded the use of tiebacks in this area. A depressed basement area approximately 16 feet below the typical lowest basement level also added to excavation design difficulties along Boylston Street.

To perform the excavation in a cost effective manner, the Observational Method was used during construction of the excavation support system along Boylston Street. Figure 7 presents a simplified installation sequence of the support system. The project geotechnical engineer reviewed the proposed excavation design and recommended that six inclinometers be attached to the sheet piling along Bolyston Street. A series of surface reference points at varying distances from the sheeting were also installed along Boylston Street. Several of the reference points were located directly above the MBTA tunnel. Typical inclinometer survey data are also shown in Figure 7.

Although a "performance specification" was established by the geotechnical engineer, the criteria limits for wall movements were exceeded during the excavation process. After careful consideration of risk, cost and time constraints on the project, the excavation proceeded despite slightly exceeding the performance criteria. Maximum surface settlement observed directly behind the sheet piling was typically less than 4 inches. The magnitude of settlements diminished quickly with distance from the excavation; reference points located above the MBTA subway tunnel indicated settlements of less than ¼ inch. On completion of the project, no damage to utilities located along Boylston Street was observed.

125 Summer Street (1987). The 125 Summer Street excavation was constructed by the top/down method as described by Khabiri.[18] A typical lower level (below slab) excavation sequence was proposed and employed by the excavation contractor after review by the

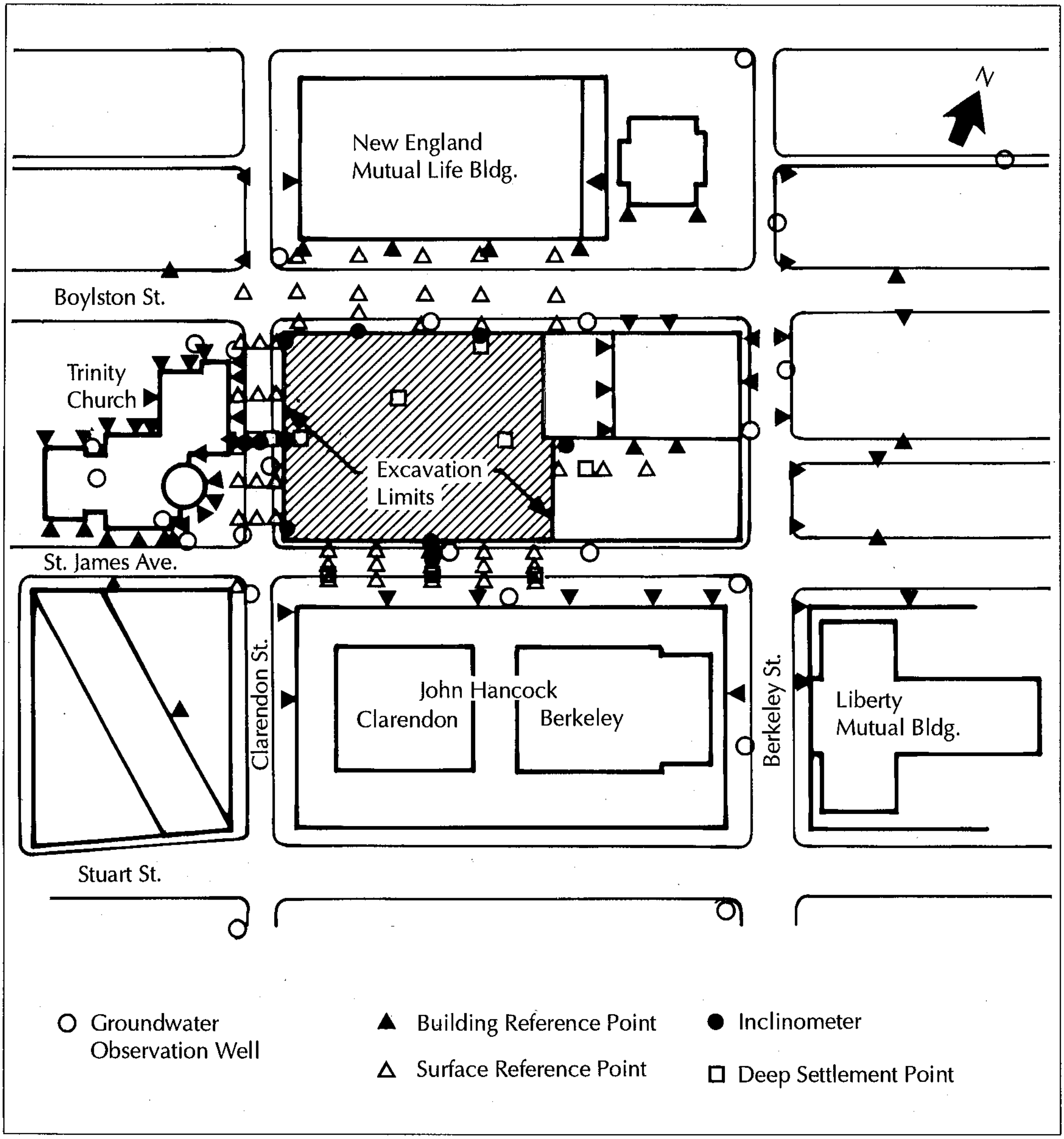

FIGURE 6. The instrumentation location plan for the 500 Boylston Street project.

geotechnical engineer. The proposed cross-sectional geometry of this scheme for the lower level 4 excavation is shown in Figure 8.

On completion of the lower level 3 floor slab, the contractor requested an adjustment to the proposed excavation sequence based on previous acceptable performance of the support system. The adjustment in the excavation scheme resulted in a more efficient and less expensive excavation operation. The geotechnical engineer reviewed the proposed adjustment in the excavation scheme given the results of previous instrumentation data. The cross-sectional geometry of the adjusted excavation scheme is also shown in Figure 8.

Movements of the reinforced concrete diaphragm wall after the completion of the lower level 3 floor slab and upon completion of the lower level 4 excavation are shown on Figure 8. The maximum ground surface settlement adjacent to the excavation upon completion was approximately ½ inch.

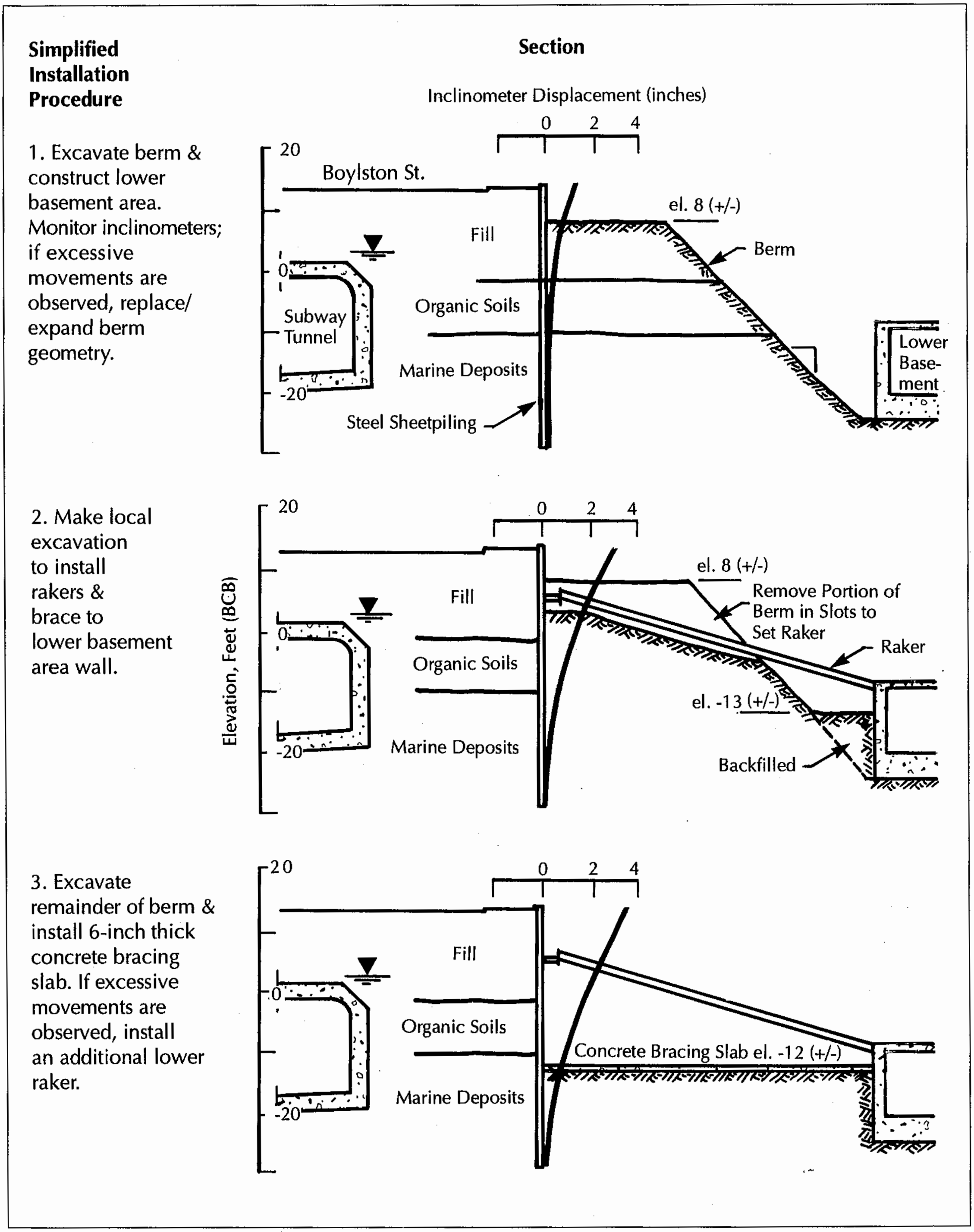

FIGURE 7. The Heritage-on-the Garden project excavation support sequence.

125 High Street (1987). The excavation for the 125 High Street Building involved the support of an adjacent four- to six-story brownstone building as shown in Figure 9.[14] The building has one basement level and is supported on granite block footings bearing on glacial till. The west wall of the building was located six to 12 feet from the excavation limits. Since the

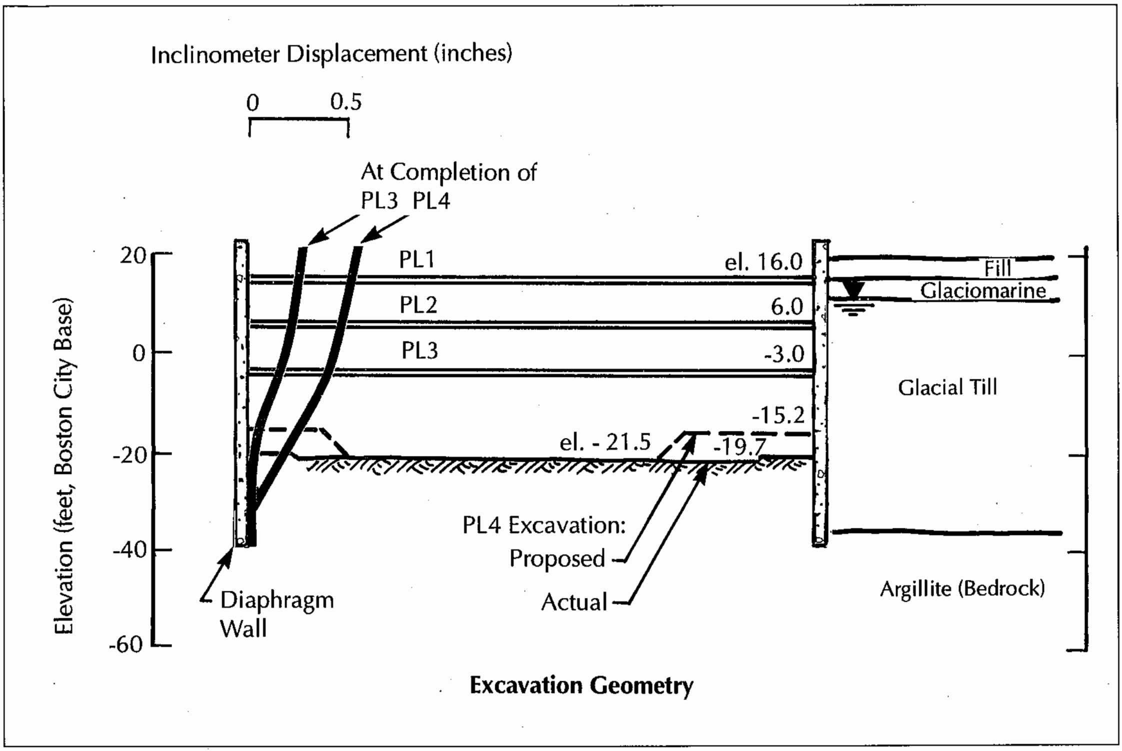

FIGURE 8. Below grade cross-section for the 125 Summer Street project.

remainder of the excavation was to be supported by a soldier pile and lagging system, with the soldier piles installed in pre-augered holes, a tangent or secant pile wall was recommended by the geotechnical engineer as an option for the support of the existing building.

The contractor elected to use a secant pile wall reinforced by double wide flange soldier beams (two W12 × 35) spaced four feet on-center. The soldier beams were inserted in three foot diameter augered holes and backfilled with 2,500 pounds per square inch (psi) concrete. The secant pile wall was braced by four levels of tiebacks having design capacities from approximately 60 to 100 kips. Figure 10 represents a typical cross-section of the support system adjacent to the building.

Since this support system was relatively unconventional in the Boston area and was extremely close to the adjacent building, instrumentation (consisting of two inclinometers attached to soldier beams and an off-set survey at each soldier pile location) was used to evaluate performance. Several building reference points were also installed on the adjacent brownstone building to measure any movements of the structure. Typical performance of the excavation support system as measured by an inclinometer survey at the completion of the excavation is shown in Figure 10. The maximum measured settlement of the brownstone building was 3⁄8 inch.

Post Office Square Garage (1989). An extensive field instrumentation, monitoring and evaluation program was implemented for this seven-level deep excavation.[20,21] Using the Observational Approach, the information collected was relied on heavily during critical stages of the construction in order to provide a reliable basis for the development of appropriate sequencing and scheduling strategies.

As with the 125 Summer Street project, the Post Office Square Garage was constructed using the top/down method. Load Bearing Elements (LBEs) were utilized to support column loads during this process. As indicated in Figure 11, LBEs were orientated parallel and offset 12 feet from the reinforced concrete diaphragm wall along Pearl Street. The LBEs were orientated parallel in this area to minimize interfer-

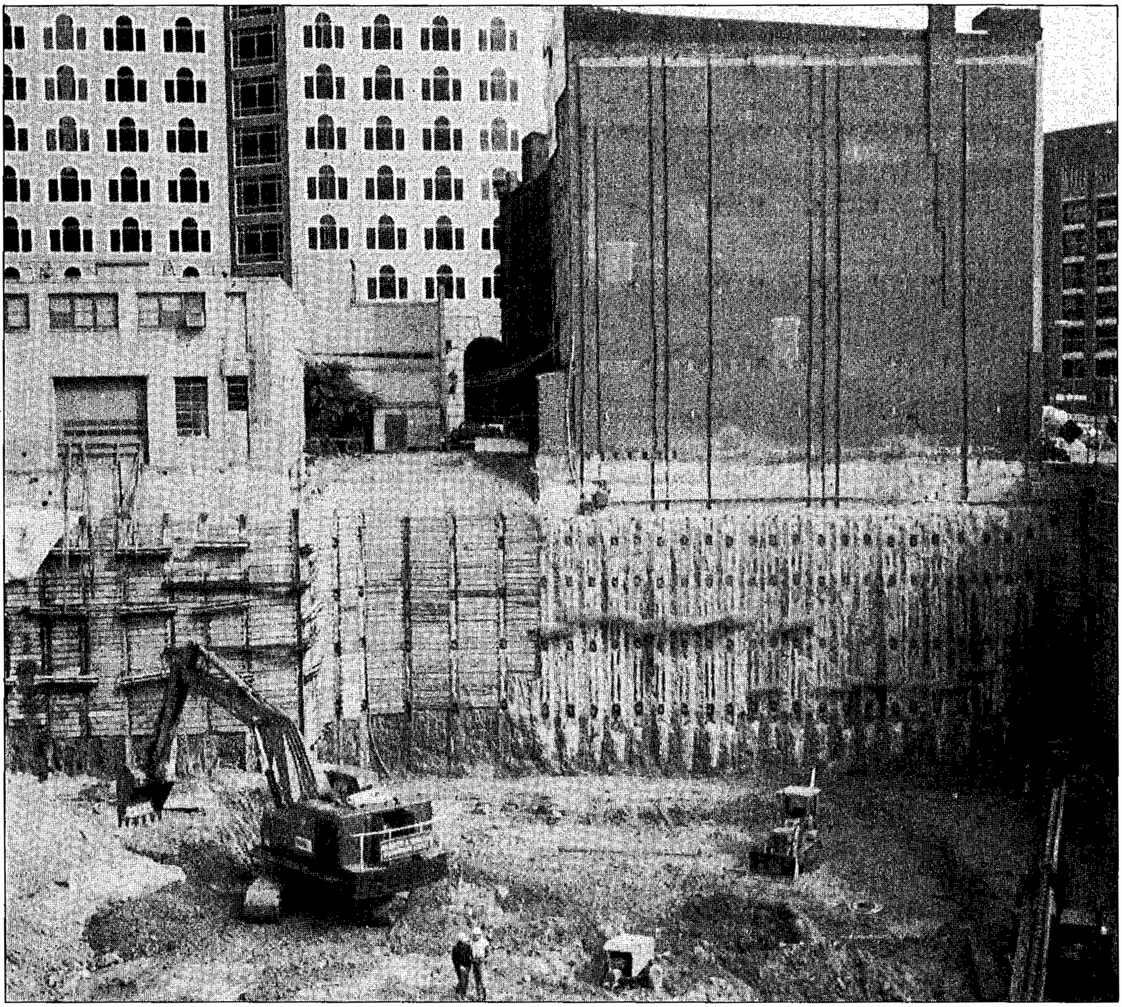

FIGURE 9. A view of the brownstone building abutting the 125 High Street excavation.

ence with two 115 kilovolt electrical lines that were temporarily supported off the diaphragm wall along Pearl Street. The electrical lines were located four to six feet from the diaphragm wall.

After the completion of the diaphragm wall, LBE installation along Pearl Street, as shown in Figure 12, generally proceeded from the Milk Street end of the site towards Franklin Street. During initial LBE installation and subsequent site excavation in this area, larger than anticipated lateral movements of the wall were observed based on inclinometer readings. It was believed that the excavation for LBEs parallel to the Pearl Street wall had effectively reduced the passive resistance of the soil adjacent to the diaphragm wall, thus leading to the unanticipated movements.

Based on the observed movements of the diaphragm wall along the northern end of Pearl Street, it was determined to adjust the orientation of any remaining LBEs that had not been installed along Pearl Street. These LBEs would be situated perpendicular to the diaphragm wall in order to limit the loss of passive resistance and allow for a greater arching effect of the soil. Only three LBEs at the southern end of the site were able to be adjusted due to space constraints imposed by the two 115 kilovolt electrical lines.

222 Berkeley Street (1989). The experience gained from observing the performance of the excavation support systems constructed along Boston's Boylston Street (Four Seasons Hotel,

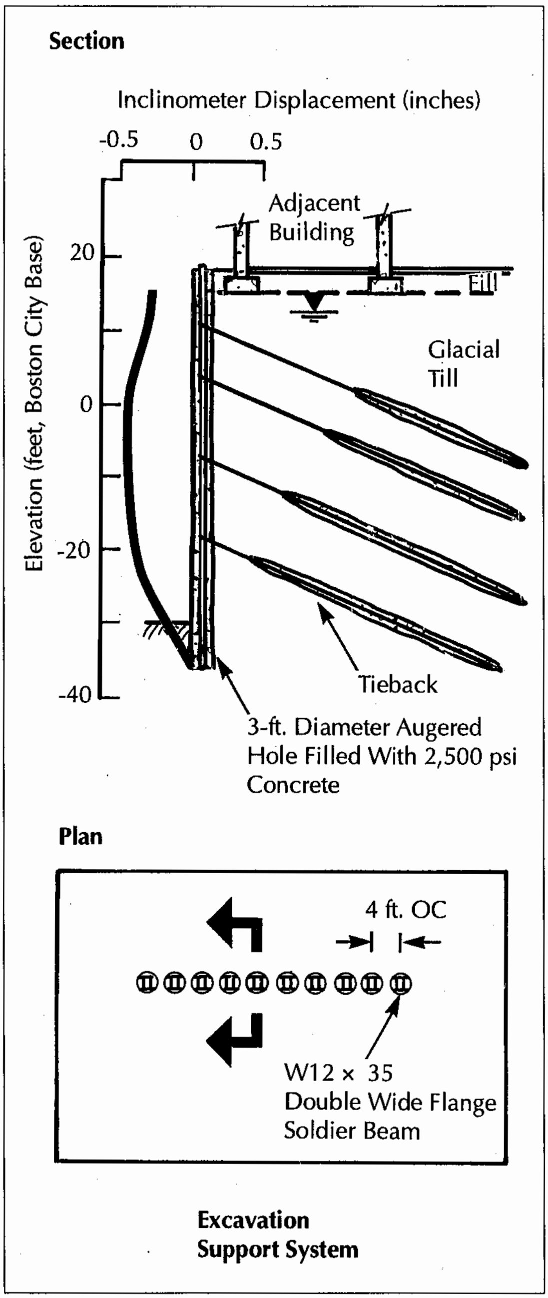

FIGURE 10. Secant pile wall details for the 125 High Street project.

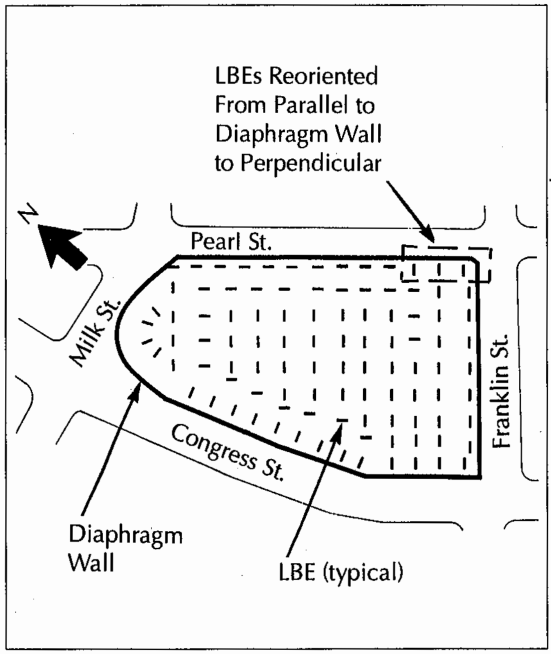

FIGURE 11. The foundation plan for the Post Office Square Garage.

Heritage-on-the-Garden and 500 Boylston Street) was used as a basis to develop an alternative approach for support of the 222 Berkeley Street excavation.[14]

The existing MBTA Green Line subway tunnel along Boylston Street limited potential options for economical support of the excavation. To overcome this constraint, the system incorporated three levels of tiebacks to support the upper 20 feet of the excavation. The lower portion of the excavation was supported by two levels of internal pipe struts. The excavation support system along Boylston and Berkeley Streets is illustrated in Figure 13. A typical cross section of the support system is shown in Figure 14.

The tiebacks were approximately 20 feet long and grouted the full length to develop design capacities ranging from 10 to 35 kips. The purpose of the tiebacks was to utilize the soil behind the sheet piling in order to support the upper portion of the excavation. To facilitate this approach, the tiebacks were closely spaced (approximately three feet on center horizontally, five feet vertically) and regrouted under pressure at least four to five times to create a stabilized soil mass.

Satisfactory performance of the system was indicated by inclinometer and reference point data. Typical inclinometer results during two excavation stages are shown in Figure 14. Adjacent ground surface settlements along Boylston Street at the completion of the excavation typically ranged from ½ to 2 inches.

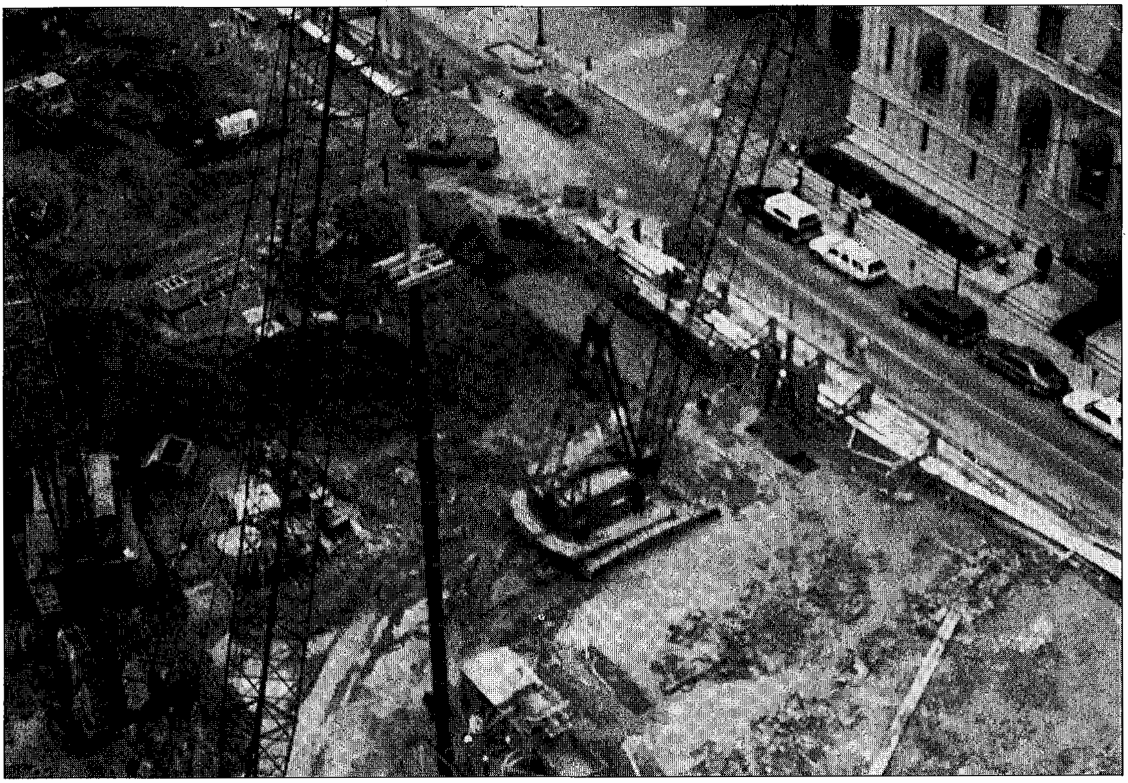

FIGURE 12. LBE installation along Pearl Street for the Post Office Square Garage.

FIGURE 13. A view along Boylston and Berkeley streets of the excavation support system for the 222 Berkeley Street project.

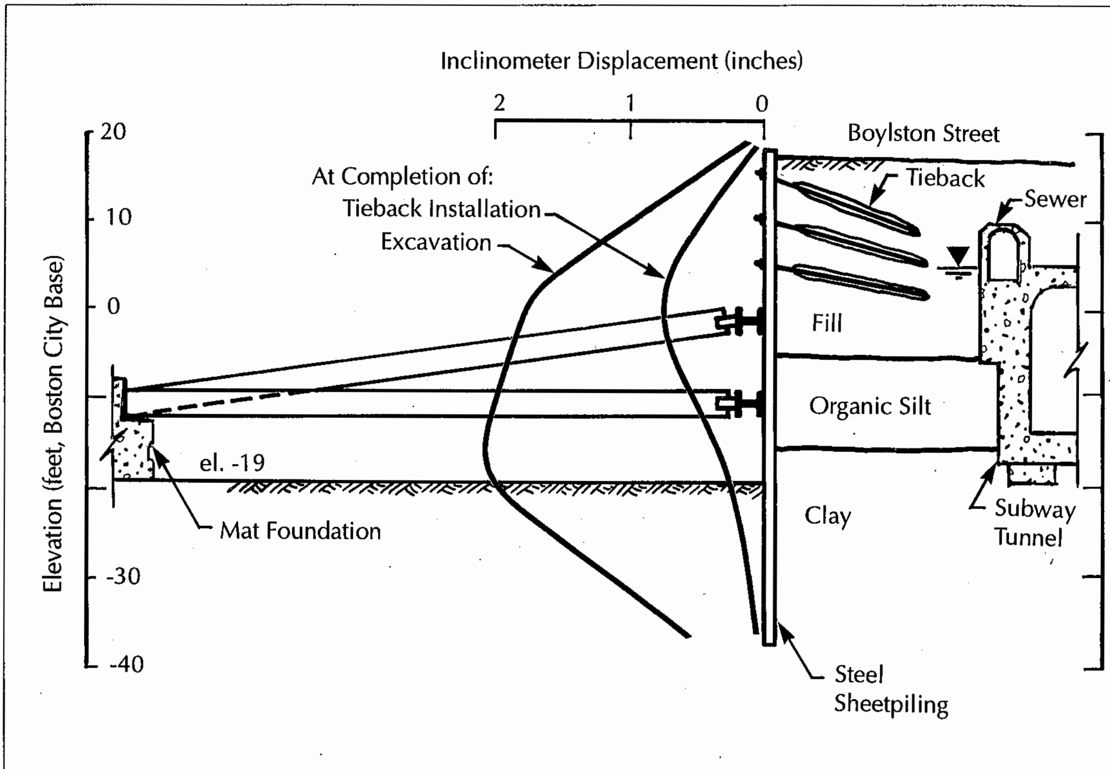

FIGURE 14. A cross-section of the excavation support system for the 222 Berkeley Street project.

Conclusions

Based on experience accumulated from numerous instrumented projects in Boston, excavation-related movements of adjacent streets, utilities and buildings are often inevitable. The magnitude and impact of these movements are generally a function of several factors that include:

- Existing subsurface conditions
- Excavation depth and geometry
- Construction workmanship
- Type of excavation support system selected
- The nature and condition of adjacent facilities.

The use of geotechnical instrumentation to monitor deep excavations can provide real-time data to quantify and to avoid potentially adverse conditions.

As illustrated in the case studies presented, instrumentation programs provide many benefits. They are effective in monitoring the performance of unproven excavation support systems or construction processes. Proper interpretation and evaluation of instrumentation data can result in adjustments to construction procedures that may limit adverse excavation effects and/or reduce construction time and costs. Relations with owners and occupants of neighboring structures, as well as government agencies and public/neighborhood organizations, can also be enhanced.

The upcoming Central Artery/Tunnel project provides major challenges for the effective use of instrumentation. Innovative design and construction approaches can be adopted more readily when appropriate instrumentation monitoring programs are employed. The collection, presentation, interpretation and construction response to instrumentation data, well coordinated among all parties, can contribute significantly to a cost effective engineered solution and reduce risks.

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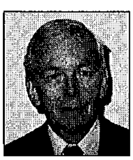

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