Protection of historic urban structures during adjacent construction

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ABSTRACT: Protection of existing structures during adjacent construction is a common problem confronted by engineers and architects in urban environments. The problem is considerably more complicated when the existing structures are older, historic structures or structures in historic districts due to the brittle materials (brick masonry, terra cotta, and plaster) traditionally used in their construction, non-redundant types of construction, age of the structures, and uncertainties in the current condition of the structures. Combining these factors with the potential for undocumented modifications to older structures, make these structures potentially more susceptible to damage from adjacent construction than new structures. This paper reviews the potential impact of adjacent construction on existing structures as well as published guidelines for the protection of existing structures during adjacent construction including demolition of adjacent sites, excavation, underpinning, installation of piles, deep foundations, site dewatering, and envelope protection during construction of the new structure above grade.

1 INRODUCTION

The construction of new structures adjacent to existing is common, particularly in urban environments. This is potentially problematic because of the need to minimize the impact of the new construction on the existing. Historic structures and structures within historic districts are potentially more susceptible to construction damage due to the brittle materials (brick masonry, terra cotta, and plaster) traditionally used in their construction, non-redundant types of construction, the age of the structures, and uncertainties in the current condition of the structures, combined with the potential for undocumented modifications to older structures, make these structures potentially more susceptible to damage from adjacent construction than new structures.

Construction can result in damage to the structure, envelope and/or finishes in adjacent buildings. “Structural” damage affects the capacity of the primary or secondary support for the building. Damage to the “envelope” is typically non-structural in nature and includes cracking of exterior finishes, mortar joints, spalling, debonding, extension of excising cracks and other forms of damage. Because the envelope is typically the primary waterproofing system for the building, this type of damage may develop into structural damage if left untreated. Corrosion of embedded iron or steel structural components and deterioration of masonry through freeze-thaw cycling are typical where envelope damage is not addressed. On many historic structures, the building envelope is also the building structure; so structural damage may include loss of bearing, failure of members, and building collapse. Cosmetic damage adversely affects the appearance of a structure without a decrease in the structural performance of the building or its weather resistance. Older, heavily ornamented structures are particularly susceptible to cosmetic damage; both envelope and cosmetic damage negatively affect the historic character of these structures.

2 ADJACENT CONSTRUCTION EFFECTS ON EXISTING BUILDINGS

The most significant impact of adjacent construction will typically occur during demolition, excavation and foundation construction operations. Based on our experience the following foundation construction activities will likely produce the most significant effects on the existing buildings:

- Installation of piles using vibration or impact methods around the site
- Excavation of the site using large equipment; rock removal; demolition of existing building foundations; etc.
- Underpinning of existing foundations
- Installation of new deep foundations
- Dewatering of the site (if required)

The following sections describe the effects of demolition, construction vibrations and underpinning on existing structures.

Table 1: Summary of Construction Vibration Limits

Standard	PPV[1] Limits in. / sec.	Frequency (Hz)	Duration/ Building or Soil	Comments
United States Bureau of Mines - 8507	0.18 to 0.5	1 to 2.5	Blast	Linear slope
	0.5	2.5 to 10		
	0.5 to 2.0	10 to 40		Linear slope
	2.0	> 40		
New York City TPPN # 10/88	0.5	none	Historic Buildings	0.25" max. movement
California Dept. of Trans.: Caltrans TAV- 02-02-R9601	2	blast	Residential	Technical advisory
	0.2	continuous	Ruins and Ancient monuments	
	0.08	continuous		
	0.2 – 2.0	pile driving	Well engineered structures	
	0.3	pile driving	Normal dwellings	
Mass. Highway Dept.: Central Artery / Tunnel	0.2	1 – 30 Source M	Type III Building Non-engineer w/ plaster finishes	Source M includes vibratory pile installation
	0.12	1 – 30 Source M	Type IV Building – Highly susceptible to damage	
Swiss Standard SN 604312[2]	0.12	10 - 30	Steady state / Vulnerable to vibration	Buildings which are especially sensitive or worthy of protection
	0.12 – 0.5	30 - 60		
	0.3	10 – 30	Transient / Vulnerable to vibration	
	0.3 – 0.5	30 - 60		
DIN 4150	0.12	< 10	Short term	Particularly sensitive to vibrations
	0.12 – 0.3	10 – 50		
	0.3 – 0.4	50 - 100		

1. PPV – peak particle velocity (1 inch / second = 25.4 mm /second)
2. Referenced in Kelley, P.L., et al, "Building Response to Adjacent Excavation and Construction," Effects of Construction on Structures, Geotechnical Special Publication No. 84, ASCE 1998, pp. 80-97.

2.1 *Construction Vibrations*

Construction vibrations are created when construction materials or equipment impact soil or rock creating localized displacements in the material. These displacements propagate through the ground, and result in the vibration (excitation) of buildings. The propagation and attenuation (decrease in intensity over time) of the vibrations through a material (soil or bedrock) is a function of the material type, material density, degree of compaction and distance from the source of the vibrations. Generally, greater attenuation of vibrations occurs in soil when compared to bedrock.

In terms of vibrations, both the magnitude of ground vibration and frequency content (dominant frequencies) are of interest. The magnitude of the ground motion is typically expressed in terms of ground velocity (distance / time). Both the frequency of the ground motion and the ground motion velocity affect the displacement of the ground at the point of measurement.

The vibration of a structure is primarily determined by the ground motion frequency. Both the ground vibrations transmitted through the soil and underlying rock will contribute to the vibrations of the structure. When the ground motion (input frequency) matches a natural frequency of a structure, a condition known as resonance occurs. Resonant or near resonant conditions will result in large amplitude displacements of a structure. In a complex structure the individual components of the structure (such as the towers, machine rooms, or other components) all have natural frequencies which can be excited by ground motion. Additions or other alterations (common in historic structures) also may complicate the response of a structure.

3 SETTING LIMITS

To prevent damage from construction-induced ground vibration, limits are typically placed on the maximum ground velocity as a function of the frequency content of the ground motion. These values are developed from experience with protection of existing structures, and are therefore empirical in nature. The values also depend upon the vibration source, soil type(s) and structure condition (Bachman et al, 1995).

Acceptable vibration limits vary significantly depending upon the type and character of the structure under consideration. Nearly all of the commonly used vibration standards recognize the need for lower vibration limits when dealing with older and historic structures. There is no single standard criterion for allowable vibration levels. While this makes the process of identifying a standard for a project more difficult, it allows rational standards to be adopted for the particular project and probable extent of damage to adjacent structures.

Table 1 provides a summary of allowable construction vibration levels from a variety of references. As seen in the table, significant variations exist in the allowable vibration levels. Some of the standards include different allowable vibration limits depending upon the expected duration of the construction operation. This accounts for the greater damage produced by long-term (steady-state) vibrations when compared to short-term vibrations of similar magnitude. Examples of construction operations producing long-term / steady-state vibrations include vibratory installation of sheet piling, pile driving, and vibratory compactors. Short–term vibrations are produced during blasting operations, dynamic soil compaction or by other means.

The most appropriate standards for the protection of historic structures are the standards which have been specifically developed for the protection of older, damaged or vulnerable structures. These include the recommendations contained in the CALTRANS technical advisory, the standards developed for the Central Artery / Tunnel project and the German and Swiss Standards. The USBM recommendations were developed from extensive data obtained on residential buildings subject to vibrations from blasting (Siskind, 2000). Significant differences may exist between the residential structures examined by USBM (disbanded in 1995) and fragile historic structures. There are also differences in the frequency and duration of blast versus construction induced vibrations. Accordingly, these are the least appropriate standards for protection of historic structures.

The lower vibration limits contained in the Swiss, German and Central Artery / Tunnel standards have been shown to be effective in preventing damage in existing structures from construction vibrations in urban environments (Kelley, et al, 1998 and Glatt, et al, 2004). In each of these research reports, no damage was observed in structures when the construction-induced vibration levels were less than the values contained in the German and Swiss Standards.

New York City guideline (TPPN #10/88) contains specific recommendations for monitoring of historic structures located within 90 feet of new construction—the typical width of the major north-south roadways in Manhattan. While the recommendations contained in the guideline are generally appropriate for protection of existing structures, the vibration limit of 0.5 inches per second may not be sufficient to preclude damage in relatively fragile historic structures. Further, while the research supporting the codification of the vibration limit (and the limits on settlement, see below) appears to be sound, the very codification of these limits without specific follow-up study to confirm their appropriateness for a broad range of historic structures makes adopting project-specific limits that differ from the TPPN difficult.

3.1 *Underpinning*

The primary concern associated with underpinning (and dewatering) of existing buildings is the settlement of the structures. Some amount of settlement occurs in nearly all underpinning projects. Any settlement, particularly differential or nonuniform settlement, can result in damage both to structural and non-structural elements of a building. The amount of settlement can vary extensively depending upon the building conditions, soil types, construction practices and workmanship. The rate of settlement can also vary significantly between structures, with the settlement potentially continuing after the underpinning work has been completed. The variation in rate of settlement occurs as a consequence of the shifting of foundation loads to different soil strata, changes in soil stresses on the newly loaded strata, and variations in time-settlement properties of soils.

To monitor the settlement of buildings, surveying methods are typically used. Prior to the start of underpinning, a baseline survey of the building is performed. The baseline survey will include the installation of monitoring targets on the buildings. During the subsequent construction operations, the elevation surveys can be repeated to determine the extent of building settlement. More frequent surveys may be required at the onset of the underpinning. The surveys should also be repeated whenever construction operations are halted because of excessive vibrations.

A maximum horizontal and vertical movement of 0.25” (6.35mm) is allowed in NYC TPPN #10/88. However, absolute limits on allowable displacements are difficult to establish. Settlement limits need to be based upon the in-situ condition of the structure, and should reflect the type of construction present. Large settlements, significant changes in crack sizes or other types of building displacement will require investigations to determine the causes and appropriate remediation.

4 PROTECTION OF ADJACENT STRUCTURES DURING CONSTRUCTION

The protection of existing construction structures requires a balance between providing safe limitations on vibration levels without precluding cost-effective construction. Construction vibration limits must be established for specific structures based upon the fragility of the existing structure and expected construction vibrations. Effective protection plans include limits on vibrations as well as recommendations for preconstruction surveys, monitoring frequency during construction, reporting and notification procedures, response for a sliding scale of damage and other considerations.

4.1 *Preconstruction Condition Survey*

Prior to starting vibration producing construction operations, preconstruction surveys are required. These surveys are used to establish a baseline condition of the structures prior to the start of construction. Typical information recorded during preconstruction surveys includes the following:

- Description of the building, building layout and site plan
- Type of construction
- Approximate age of construction
- Type of foundations
- General condition of the building
- Location, width and orientation of visible defects/cracks
- Location of loose materials
- Location of previous repairs
- Distance to construction operations

The preconstruction surveys focus on documentation of existing defects and cosmetic damage in both the common areas and individual building units. Accurate preconstruction surveys of existing damage are essential to prevent spurious claims of new damage occurring as a result of the new construction. The results obtained during preconstruction surveys can be used for comparison purposes in the event of reported damage during construction.

During the preconstruction surveys, any potentially loose or damaged materials should be identified. If possible, these materials should be made safe prior to starting construction. Additionally, consideration should be given to retrofitting hanging mechanical equipment to prevent damage from sway.

4.2 *Visual Surveys During Construction*

During the construction period, routine visual surveys are recommended to allow for any changes in condition to be documented. These surveys should focus on existing conditions identified during the preconstruction surveys to see if any changes have occurred, and evaluating if new damage is present. Depending upon the ongoing construction activities, the visual surveys should be completed on at least a weekly basis. Additional surveys will be required .within 12 hours of exceeding a critical vibration threshold. A survey report should be prepared after completion of each survey with copies distributed to the contractor, building owners and developers.

4.3 *Construction Vibration Monitoring System*

To allow for a rapid reaction to excessive vibrations, an integrated monitoring system is needed to allow for notification of the monitoring engineer, contractor and owner when critical vibration thresholds are exceeded. The integration will require the connection of all seismographs to a central data acquisition system which has the capability to immediately notify the monitoring engineers and contractor via telephone/email when critical vibration levels are exceeded. The vibration monitoring system should be installed and operational at least thirty days prior to the start of construction. This will allow for baseline monitoring results to be established.

4.4 *Crack Monitoring*

To accurately determine if changes in existing cracks occur, the installation of crack monitors is recommended. The exact locations of the crack monitors should be determined during the preconstruction surveys of the buildings. These monitors can be either visual (tell-tale type) monitors or electronic monitors that are linked to the vibration monitoring system. Additional crack monitors may be required in the event of new crack formation during construction.

The crack monitors should be examined during all routine surveys of the building condition. Any changes in crack size should be included in the survey report. Significant changes in crack size will warrant further investigation to determine the cause of the changes.

4.5 *Human Vibration Perception*

Effective construction protection plans require the education of owners/tenants to discern the difference between perceptible vibrations and potentially damaging vibrations. Human perception to vibrations begins at much lower levels than those shown in Table 1. Vibrations with a peak velocity as low as 0.02 inches per second are perceptible to a standing person, while a vibration velocity of 0.26 inches per second may be considered disturbing or unpleasant (Bachman, 1995). The human perception of vibration, at 0.02 inches per second, is one-sixth the 0.12 inches per second value shown in Table 1 as a recommended vibration limit.

The low threshold for human perception of vibration highlights the need for automated monitoring of these vibrations, and the need to establish baseline vibration levels in the buildings. To establish baseline vibration levels in the buildings, the monitoring should be started a minimum of thirty days prior to construction. During the baseline period, the monitoring system should be used continuously to allow for all sources of "normal occupancy" vibrations to be documented. These sources may include subways, traffic, elevators and other sources. Results from these baseline studies should be presented to the building owners to allow for a feel of "typical" vibration levels to be developed.

5 CASE STUDIES

Construction protection plans have recently been developed for two projects in the New York City area. One of the projects involved the protection of two historic structures adjacent to a proposed high rise tower; the other involved the protection of existing buildings in a historic district.

5.1 *Historic Buildings*

The existing buildings represent well preserved examples of early skyscraper construction in New York City. Building 1 (Figure 1), built from 1878 to 1880, was originally ten stories tall, two additions increased the height to 15 stories. Building 2 (Figure 2) is 21 stories tall, and was originally constructed in the early 1890s. Both buildings have been converted from their original commercial office use to residential.

To assist in the development of the protection plans, limited surveys were completed in both buildings to assess the construction types, current condition and other factors. The surveys indicated that the buildings were generally in good condition and were well maintained. However, potentially susceptible details were observed in both buildings. These details included the prior underpinning of portions of Building 2 to accommodate subway construction, cast iron structures, and remnants of previous common wall construction.

Building 1 was largely constructed using brick masonry construction for the exterior walls. The floors appear to be constructed using closely spaced wrought iron or steel beams with barrel vault construction between the beams. Decorative features on the roof include ante-fixes on the parapets. These features were recently replaced using replicas of the original construction, substituting synthetic materials for the original terra cotta.

Building 2 was constructed using a combination of steel and masonry construction. The building is clad with a mix of gray granite, brick and terra cotta. The three level penthouse is wrapped with an ornate copper fascia with terra cotta caryatids, in the shape of winged angels, at the corners of the penthouse (Figure 4). The caryatids are topped with gold spheres. The caryatids are currently strapped to the building (Figure 5) and show signs of cracking and spalling.

The historic nature of the buildings and the highly ornate exterior facades lead us to recommend conservative vibration limits. Table 2 shows the recommended vibration limits for the buildings. These limits were largely based upon the German, and Swiss Standards shown in Table 1, and are also consistent with NYC TPPN # 10/88. Table 2 also contains recommendations for visual surveys of the buildings based upon the recorded level of vibrations, and an upper vibration limit at which all construction operations should cease until an inspection of the buildings can be performed. If new damage is observed during inspections of the buildings, more stringent vibration limits will need to be imposed (consistent with the recommendations contained in NYC TPPN # 10/88). In addition to the monitoring program, the following additional recommendations were made:

5.2 *Historic District*

The construction of a new mezzanine and stairway has been proposed to add to an existing mass transit system. The proposed new construction will be located within a historical district recognized by both New York City and the National Register of Historic Places. To insure the protection of the buildings within the project area, and to assess the need for possible limitations on construction, a construction protection plan was commissioned by residents of the district.

The buildings in the area were generally federal style buildings (Figure 6), and were constructed starting in the 1820s. Signs of modifications and alterations from the original construction were visible in the majority of the surveyed buildings. Typical modifications included changes to the front facades to allow for retail space on the ground level, and conversion of the buildings into multi-unit apartments.

During the site evaluation, the foundations of the federal style buildings were observed to be highly susceptible to damage. These foundations are constructed with loose stone, rubble type materials and can be easily damaged by construction induced vibrations, or settlement of the surrounding soil (Figure 7). The potential for damage is exacerbated by the extensive erosion of mortar observed during the survey.

To prevent construction damage to the existing buildings in the district, limitations are required on both the vibrations and tolerable settlement produced by the construction. These limitations should apply to all buildings within 90 feet of the construction area. Table 3 shows specific vibration limits from the construction protection plan developed for the historic district. These limits require damage surveys at lower thresholds than those shown in Table 2 due to the more fragile nature of the buildings. The remaining facets of the program were similar to those discussed above.

Table 2 – Recommended Vibration Limits for Historic Buildings / Districts

Peak Vibration Level (in. / sec.)[1]	Reporting	Engineer Action	Contractor Action
≥ 0.05	Engineer	Routine inspection	None
≥ 0.12	Engineer/Contractor	Daily inspection	None
≥ 0.50	Engineer/Contractor/Owner	Priority[2] survey	Cease vibration producing work[3]
≥ 2.0	Engineer/Contractor/Owner	Priority survey	Cease all work[4]

Table 3 – Recommended Vibration Limits for Historic District Buildings

Peak Vibration Level (in. / sec.)[1]	Reporting	Engineer Action	Contractor Action
≥ 0.05	Engineer	Daily inspection	None
≥ 0.12	Engineer/Contractor	Priority[2] survey	None
≥ 0.50	Engineer/Contractor/Owner	Priority[2] survey	Cease vibration producing work[3]
≥ 2.0	Engineer/Contractor/Owner	Priority survey	Cease all work[4]

1. Vibration level recorded at individual building (1 inch / second = 25.4 mm /second).
2. Survey within 12 hours of vibration limit being exceeded.
3. Vibration producing work should be stopped and alternate construction methods used.
4. All vibration producing work should be stopped until after completion of engineers survey and alternate construction methods used.

6 SUMMARY

Protection of historic structures and structures within historic districts during adjacent construction is frequently required in urban areas. The protection of these structures is more demanding than protection of newer structure. This is because of both the fragile nature of these structures, and the need to prevent both structural and cosmetic damage from occurring. Monitoring and protection plans for these structures require an accurate assessment of the structures current condition and the development of appropriate construction vibration limits. The implementation of monitoring and protection plans will not preclude damage from occurring during construction. The monitoring and protection plan allow for a rational quantification of the impact of the construction on the buildings. The efficacy of the protection measures will be further discussed in our presentation.

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