Targeted Vibration Control During Internal Construction

The Neue Galerie New York

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Building and Project Description

Any major construction project presents a number of challenges, which are even more complex in an operating museum. Aside from technical issues, which are inherent to all museums, protection of guests, staff, the building, and works of art must be considered, along with logistics. At first take, one may reason that projects at smaller institutions would be easier to manage, but that is only true in terms of their magnitude. The issues are the same, and in some ways may be more complicated, due to limited access, and proximity of work to critical areas.

The Neue Galerie New York is a 15-year-old house museum located along Museum Mile in Manhattan (Figure 1). The supplemental chiller project was in the planning stage for several years. Architects were chosen based on their extensive experience with the Landmarks Preservation Commission; as Neue Galerie is a landmarked building within a historical district, the new rooftop condenser would need approval. Mechanical Electrical Plumbing Structural (MEPS) consultants were chosen based on their experience working on museum projects, specifically in the New York metropolitan area.

Although there was a relatively small amount of demolition and structural work, several factors led to the decision to engage Wiss, Janney, Elstner Associates (WJE), an engineering firm specializing in the investigation, testing, and repair of existing buildings, including management of construction vibrations at museums. Firstly, several galleries below the worksite were to remain open, one of which contained the iconic painting *Woman in Gold* (1907) by Gustav Klimt, and other irreplaceable items in the collection. Secondly, although there were no visible signs of structural failure, we had to verify how vibrations would transmit through, and possibly affect, the 103-year-old building. Thirdly, the majority of the work would take place within 20 feet (6 meters) of two adjacent occupied residential buildings and the existing chiller plant, and we had to be sure that there would be no impact.

Figure 1. General view of the Neue Galerie New York.

There were many technical and logistical challenges involved, particularly the need to have a comprehensive understanding of the possible risks to staff and visitors, to the Neue Galerie's irreplaceable works of art, and to the landmark building itself. This complexity was compounded by the need to keep the museum running, while getting the job done within strict time constraints.

Initial plans were to have a modular chiller with an enclosure fabricated offsite and lifted into place, requiring relatively simple mechanical and electrical attachments. This would have had very little impact on museum operations and would have greatly simplified structural and waterproofing issues. Design considerations, including strict noise criteria, rendered this method untenable; a much more invasive process had to be undertaken. Once the equipment was selected, the architectural and structural concerns had to be addressed, in addition to securing approvals from the Department of Buildings and the Landmarks Preservation Commission.

Cooperation and communication between all departments were critical, and swift once the approvals were obtained. The museum's registrar and curators were involved in the process, and were very instrumental in getting several issues resolved. The strong desire to keep the museum partially opened was contingent on having *Woman in Gold* and a number of other irreplaceable works on display.

In the end, we were able to close the galleries directly below the work area, keeping only two critical galleries open. Controlling and monitoring contractors—while protecting the art and building from normal hazards such as fire, water, air contaminants, etc. during the construction process—was accomplished by enhancing our already tight protocols. The more challenging aspect was vibration monitoring and control. A customized plan was developed to establish pre-construction conditions, working parameters, and a system that would immediately stop work if threshold parameters were exceeded.

In order to execute the more elaborate project, a three-phase plan was developed.

Pre-construction preparation phase

This phase occurred during removal of the spring exhibition, and prior to construction operations (approximately 60 days). The major work tasks included:

- Construction of a temporary office space within the building.
- Enhancement of the IT network to be VPN-capable.
- Development and implementation of a construction access and emergency plan, including special training for security and facilities staff.
- Complete overhaul and testing of the only elevator in the building, to ensure its reliability throughout the project.
- Complete servicing and protection of the building mechanical plant immediately adjacent to the construction area, which had to remain functional and accessible for continuous operation, monitoring and servicing throughout the project.

Construction phase

The second phase had to be completed within a 30-day restricted window, between removal of the spring exhibition and in advance of the installation of the new exhibition. This time constraint left the project with little or no room for error. The goals achieved by the second project phase were:

- Demolition of parapet, roof, and load-bearing walls.
- Maintenance of a watertight building envelope throughout.
- Installation and waterproofing of a new structural steel-supported exterior wall and roof.

Concluding Phase

The final project phase began after the opening of the fall exhibition. It involved completing the necessary electrical work, followed by the actual installation of the chiller and rooftop condenser—all concluding before the holiday rigging moratorium and a high volume of museum visitors. Work over the winter months continued, and included finalizing details of electrical work, pipe-fitting, and finishing work in preparation for commissioning the new systems in early spring.

Vibration Control—General Methodology

Given the strict limitations necessitated by the nature of the facility, very careful control of construction vibrations would be required during the internal demolition and structural work associated with the second phase. As detailed in previous articles authored by WJE,[1, 2, 3] the five general steps summarized in Table 1 should be considered

Table 1
General Steps for Vibration Control During Museum Construction Projects (after Johnson, et al, 2013)

Step 1 Field vibration trials using actual construction methods	• In-situ vibration measurements at the museum using artificially-induced effects to simulate construction activities, if warranted. • Ambient (background) vibration measurements within the museum. • Estimation, based on the test data, of the actual levels of vibration that the Museum is likely to experience, due to planned construction activities.
Step 2 Preconstruction planning	• Selection of vibration criteria for the project, considering the following: —Potential damage thresholds and typical art/building protection limits —Results of ambient vibration monitoring —Recommendations of a collections specialist or conservator regarding the specific art objects to be protected • Development of art stabilization and deinstallation plans, if any, with input from the collections specialist or conservator.
Step 3 Development of a vibration control specification	• See referenced article for details to be included, as customized for each project. • Requirements for pre- and post-construction surveys of building and works of art.
Step 4 Field vibration trials using actual construction methods	• At the start of construction, perform vibration measurements in the museum during simulated activities, using actual equipment and methods proposed for use by the contractor. • Verification that measured vibrations are within adopted protection limits.
Step 5 Vibration monitoring during construction	• Review of contractor's vibration control plan, and means-and-methods submissions. • Continuous vibration monitoring throughout the construction process within the museum (in front of art being protected). • Monitoring system providing immediate notifications of above-limit measurements, and any such events evaluated and resolved before construction is allowed to resume. • Regular inspection of art objects by Museum staff.

[1] A.P. Johnson and W.R. Hannen, "Vibration Control During Museum Construction Projects," *Journal of the American Institute for Conservation*, 2013, Vol. 52 No. 1, pp. 30-47.
[2] A.P. Johnson and W.R. Hannen, "Vibration Limits for Historic Buildings, Art Collections and Similar Environments," APT Bulletin, *Journal of Preservation Technology*, Vol. 46:2-3, 2015, pp. 66-74.
[3] A.P. Johnson and W.R. Hannen, *U.S. Practice in Vibration Control During Museum Construction Projects*, International Council of Museums Conservation Committee (ICOM-CC) conference proceedings, September 2016, Paris, France.

when protecting works of art from construction vibrations. The level of effort and details of each of these steps should be adjusted to fit the specifics of each project, and the needs of each institution.

WJE has previously published on the comprehensive application of these steps for large museum construction projects, such as the recent expansions of the Art Institute of Chicago and Saint Louis Art Museum. However, for more moderate construction initiatives—such as the chiller project at the Neue Galerie New York—a more targeted approach is often possible.

Vibration Control Approach Targeted to the Project

Vibration control considerations for the chiller project began with the Neue Galerie commissioning a preliminary assessment, which involved WJE staff visiting the museum for a day, meeting with involved parties, viewing the areas where the construction was planned, speaking with curatorial staff regarding the fragility of nearby objects, and reviewing the drawings of the existing and planned construction. A report was then prepared regarding the vulnerability of the building and collection to construction vibrations, along with specific recommendations for vibration control measures. The most significant vibration-causing activities were identified as demolition of the fifth-floor brick masonry walls (approximately 15 feet (4.5 meters) long by 12 feet (3.7 meters) high, (see Figures 2 and 3) and localized demolition of existing concrete encasements to attach new steel framing members.

Because the only access to the work area was through the inside of the building, the contractor's means and methods were limited to relatively light methods, with the largest tools anticipated to be electric chipping hammers. Based on prior experience, WJE made preliminary estimates of vibration transmission in the building. Vibration levels in the second-floor galleries where works of art would be present were predicted to be less than a conservative limit for protection of art.[4] However, it was noted that vibration transmission within an existing building is difficult to predict without site-specific testing, especially when the vibration source is within the building itself.

Since the preliminary assessment identified that the planned work would have relatively little impact on the museum collection, and after consultation between WJE and museum staff, it was agreed that the five general steps of vibration control would be consolidated into two phases: a vibration verification phase and a vibration monitoring phase, as described below.

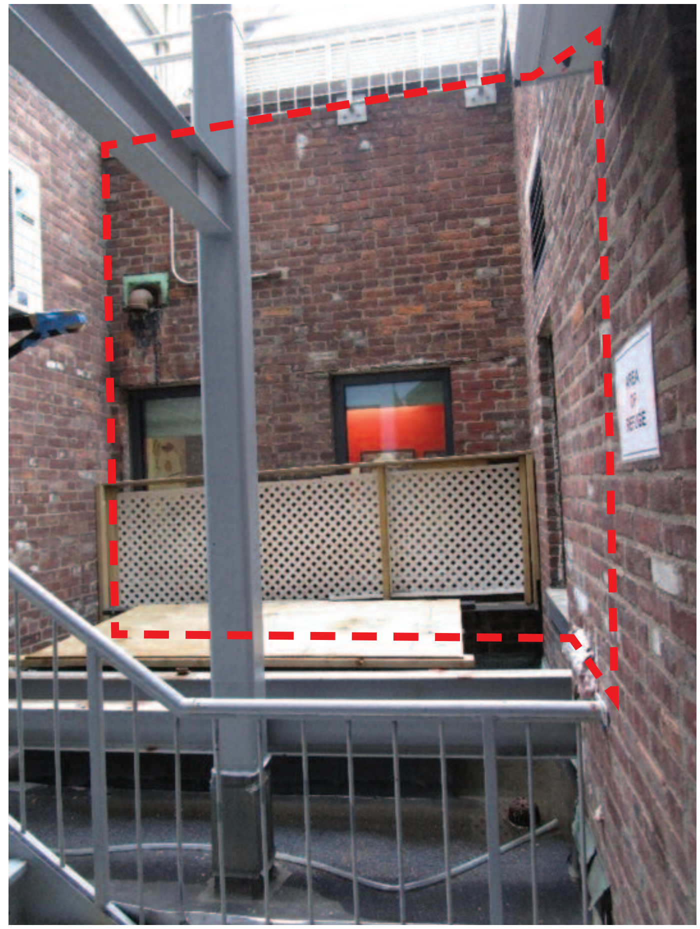

Figure 2. Brick masonry removal area at fifth floor, adjacent to new chiller location.

Figure 3. Interior view of load-bearing masonry walls to be removed on fifth floor.

[4]Several other institutions have recently used a vibration limit of approximately 0.10 in/sec peak particle velocity (PPV), typically increasing with vibration frequency, for the protection of works of art. Research conducted by the authors indicates that this is a conservative limit for the protection of art that is in reasonably sound condition. Refer to References 1 through 3 for further explanation and special considerations. Given the unique nature and value of the objects being protected at each institution, it is prudent that the museum select the vibration limit for each project, based on engineering input, evaluation of objects by art experts, and consideration of the degree of protection versus the cost of protection.

Vibration Verification Phase

Ambient vibration monitoring. First, WJE installed vibration monitors (Figure 4) at key locations in the museum, and collected ambient (background) vibration data for approximately one month. Ambient levels ranged from 0.02 to 0.07 in/sec PPV[5]—common values for buildings of this type. For comparison, human perception of vibrations begins at approximately 0.03 in/sec; a conservative limit for the protection of art objects in reasonably sound condition is 0.10 in/sec; and a limit for protection of buildings from threshold cracking in plaster wall finishes is 0.50 in/sec.

Submission review and preconstruction planning. Next, WJE reviewed the contractor's submissions and interviewed the contractor regarding their proposed means and methods. Cautions were provided to limit vibratory effects of the proposed methods, including avoiding dropping heavy construction materials from any height; limiting impact tools to electric chipping hammers and hand tools, unless specialized testing was performed to validate other equipment; using short bursts rather than continuous operation of chipping equipment; sawcutting to isolate areas prior to demolition; placing absorptive materials on horizontal surfaces where debris collects; and using debris carts with pneumatic rather than hard rubber tires. In parallel, the museum conducted pre-construction surveys of the building and collection, including inspection, documentation, and stabilization as necessary of interior finishes, light fixtures, glass ceiling panels, and similar items that might be vulnerable to vibration. Museum staff also evaluated art located near the construction, such as verifying that light objects on smooth surfaces were secured against shifting.

Vibration trials. To confirm that vibration transmission would be within acceptable limits, WJE recommended specific field trials at the beginning of the work. The contractor simulated work using actual equipment and methods, while vibrations were measured using multiple sensors placed temporarily on each floor level. As summarized in Table 2, the most significant vibrations measured during the trials were 0.085, 0.044, and 0.021 in/sec PPV on each of the floors. The largest vibrations were caused by dropping heavy debris and the impact of a sledgehammer. Work by chipping hammers produced lower vibrations (0.02 in/sec PPV maximum). The trials verified that vibrations at the location of the nearest work of art on the second floor would be well below the art-protection limit of 0.10 in/sec PPV that the museum had adopted.

Vibration Monitoring Phase

As a final safeguard to protect the works of art, a vibration monitoring system was deployed and operated continuously throughout the demolition and structural work. Based on the results of the ambient monitoring and field trials, monitors were installed at four locations: two on the fourth floor, one on the third floor, and one on the second floor near the installed art (see Figure 6). The monitoring system was networked, remotely accessible in real time, and programmed to provide immediate notifications of any above-limit measurements. Two alert levels were utilized: a lower level of 0.075 in/sec PPV to serve as a caution to

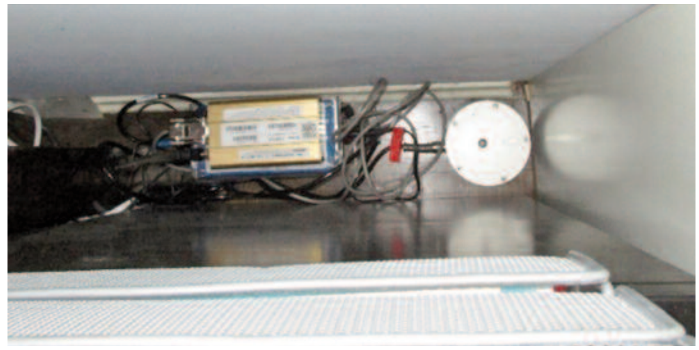

Figure 4. Looking down at typical vibration monitor installation.

Figure 5. Dropping terracotta blocks with plaster finish from a height during vibration trials.

Figure 6. Enclosure (red arrow) constructed around vibration monitor in second-floor gallery.

[5]0.10 in/sec = 2.5 mm/sec

the contractor, and a project limit level of 0.10 in/sec PPV, independent of frequency.

When the monitoring system issued an email notification that the alert level had been exceeded at a monitor, the contractor was required to stop all construction work until the vibration engineer analyzed the data and advised all parties on the cause, significance, and appropriate remedial actions. If the event was due to construction activities, the contractor was required to revise their methods before proceeding. The museum's facilities director was intimately involved in the field trials and the responses to notifications of vibration events. This greatly reduced engineering time and facilitated rapid resolution of all issues.

The maximum vibration amplitude recorded on the second floor, where works of art were present, was approximately 0.03 in/s PPV—a small margin of the art-protection limit. The vibrations recorded at the fourth floor exterior wall demonstrated that any vibrations transmitted to the abutting residential building were well below disturbing levels. Vibrations at the fourth-floor monitor, directly below the fifth floor demolition, occasionally exceeded alert levels, which served as a useful caution to the contractor.

Factors for Success

The vibration control measures devised for this project facilitated effective advance planning by the museum on the possible effects of construction vibrations, allowed the contractor to perform the construction using reasonable means and methods, and reliably protected art objects throughout the construction process. Looking back on the project, the authors attribute this success to the following factors:

- Vibration control can be targeted to suit a moderately sized museum construction project. The five general steps summarized in Table 1 are typically appropriate for a large-scale museum construction project, but a more customized, streamlined plan can often be devised for more modest construction works. Such a plan can be more economical and workable within the constraints of a smaller project.
- Trust, communication and collaboration between museum staff, consultants, and contractors are essential on any day in the work environment, and are even more important when planning and executing a major construction project in a museum.
- Re-examining and enhancing security, operations and emergency procedures is key. This includes modification of building inspections, along with scheduling extra time for training and normal building operations, as they are all affected by construction activities and vibration control procedures.
- It proved useful to have outside peer review of modified plans. No one knows museum security and operations better than museum colleagues, and they will give unbiased views.

Table 2
Maximum Vibration Levels Measured During Trials (in/sec, PPV)

Test Activity and Location	4th Floor: Gallery Below Work	4th Floor: At Exterior Wall	3rd Floor: Gallery Below Work	3rd Floor: Adjacent Atrium	2nd Floor: Gallery Below Work	2nd Floor: Adjacent Gallery
Electric Chipping Hammer						
Masonry parapet	0.008	0.009	0.008	0.004	0.007	0.004
Concrete beam encasement at roof level	0.007	0.007	0.006	0.003	0.004	0.003
Fifth-floor masonry wall, mid-height	0.018	0.009	0.012	0.004	0.005	0.003
Fifth-floor concrete slab	0.016	0.014	0.009	0.005	0.009	0.005
Heavy Debris Dropped from Height						
Chunk of terracotta dropped onto fifth floor	0.085	0.016	0.044	0.007	0.021	0.006
Sledgehammer						
Masonry parapet	0.029	0.014	0.022	0.003	0.018	0.004
On terracotta near top of fifth-floor wall	0.052	0.019	0.017	0.011	0.012	0.004
On solid masonry near bottom of fifth-floor wall	0.106*	0.031	0.044	0.007	0.022	0.004

*Based on high values, the impacts of sledgehammers were restricted to softer materials such as terracotta and plaster or brickwork that had already been broken up using chipping hammers.

- It is important for a museum to evaluate and articulate its needs and constraints to consultants and contractors, since every project is different and each facility's operation is unique.
- Finally, it is crucial to identify and hire trustworthy, excellent and appropriately experienced consultants. True professionals possess the ability and the willingness to customize their services for each project, based on its size and complexity. 🏛

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Figure 7. Completed chiller installation: from roof (left) and in new fifth-floor mechanical room (right).