Protecting Stained-Glass Windows from Vibrations Caused by Construction Operations

Author(s): Dean Koga, Erica Morasset, Raymond Pepi and David Woodham

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Erica Morasset
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Fig. 1. Windows on the upper level of the sanctuary, looking north, Congregation Shearith Israel, 8 West 70th Street, New York City, built 1897. Photograph by BCA, 2015.

With the correct monitoring program, demolition work adjacent to historic stained-glass windows does not necessarily require invasive and potentially damaging interventions.

Erected in 1897 to the design of architects Arnold W. Brunner and Thomas Tryon, the Congregation Shearith Israel at 8 West 70th Street, facing Central Park West in New York City, houses the fourth-oldest Jewish congregation in North America.[1] A New York City landmark, the building is a neoclassical masonry structure that is largely defined by the original monumental, nonfigurative windows designed by Tiffany Glass & Decorating Co., which became Tiffany Studios in 1902 (Figs. 1 and 2). The windows are character-defining elements of the sanctuary space and contribute significantly to the worship experience.

The New York City Department of Buildings, through *Technical Policy and Procedure Notice #10/88*, mandates that Construction Protection Plans (CPP) be prepared and filed to protect historic buildings from damage caused by construction on nearby structures.[2] A CPP must be prepared for buildings designated as landmarks by the City of New York that are located within 90 feet

(27 m) of a construction site. The directive sets a threshold for vibrations, but it does not take into consideration fragile objects and assemblies such as stained-glass windows. Accordingly, a separate CPP was prepared for the stained-glass windows at Congregation Shearith Israel prior to the demolition of the attached community house and the erection of a larger structure.

Building Conservation Associates, Inc., (BCA) and architect Jonathan Schloss were retained to prepare the CPP for the stained-glass windows in early 2015. The plan called for an assessment of conditions, stabilization measures, and procedures to mitigate the effects of construction vibrations, since the congregation felt strongly that, if possible, the windows should remain exposed and in place during the course of the project. Protection plans that involved entirely boarding up or removing all of the windows during the demolition work had been rejected previously by the congregation, which felt that such invasive methods would considerably reduce natural light and detract significantly from the spiritual atmosphere and worship experience. Although not the main driving consideration, removing and storing all windows off-site during the course of the work would have also increased the overall costs associated with protection. The windows had been restored approximately 20 years earlier. Since stained-glass windows are difficult to photograph, an architectural photographer began the documentation process for the current project by creating images of each window in reflected and transmitted light.

The arched windows in the sanctuary consist of steel sash set in wood frames; each window is subdivided by wood mullions to form a border of stained glass. There are operable ventilator panels within the borders and the large fixed panels, as well as in small openings in the north wall. The windows on the north and south walls extend the full height of the sanctuary, including the parts of the wall behind the balcony (Fig. 3). The windows on the east wall are narrower than the others and extend up only from the balcony level.

Fig. 2. Congregation Shearith Israel, east elevation. The synagogue faces Central Park West. Photograph by BCA, 2020.

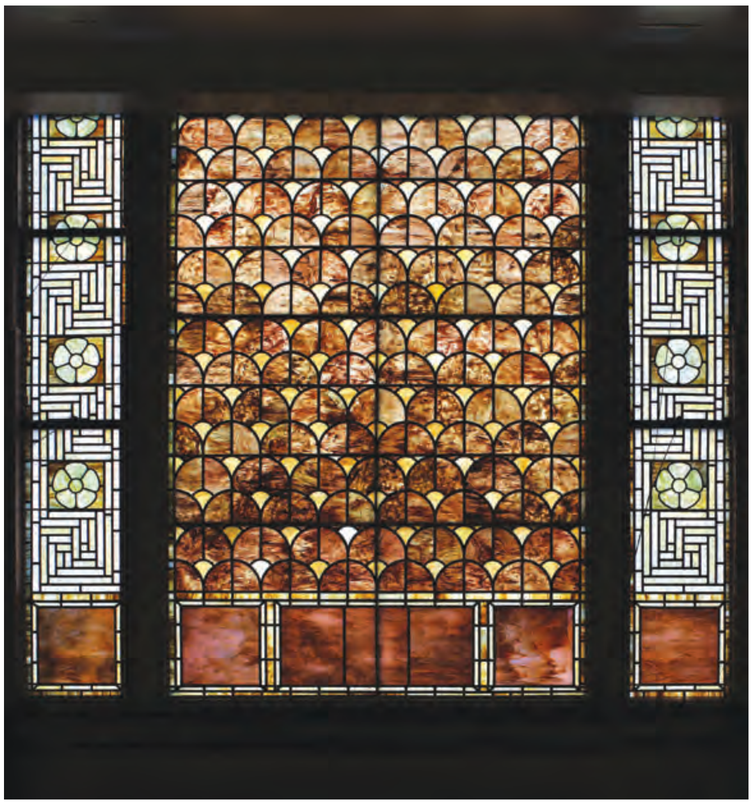


Fig. 3. Window detail, north elevation. Note the cords on the right to open and close the operable panels. Photograph by Whitney Cox, 2015.

Three narrow arch-topped windows adorn the west wall of the Little Synagogue, a small meeting room in the southwest corner of the building. The overall decorative pattern differs from that of the sanctuary, but the glass is similar, and some motifs are repeated. Operable ventilators are located only in the north and south windows. Protective glazing, fabricated of glass and set in steel sash, had been installed previously over the north and east sanctuary windows and the windows of the Little Synagogue.

As a first step, BCA documented the conditions of the windows and determined the following:

- Most windows were in good condition.
- There were many repaired cracks and a few unrepaired cracks, presumed to have propagated since the restoration work of the mid-1990s.
- The east window panels were buckled from heat generated by morning sun between the inadequately vented exterior protective glazing and the glass panels.
- There was extensive damage to two panels in the windows in the Little Synagogue.
- Some ties to the supports or saddle bars were loose, broken, or missing.
- The tall windows deflected 0.125 inches (3 mm) on average under light finger pressure on the support bars, with two windows deflecting 0.25 inches (6 mm). This observation helped to establish a baseline of 0.125 inches (3 mm) for typical deflection of the windows and identify instances where panels deflected more than the typical observed deflection.

All the conditions were entered onto the digital photographs, and the following repair and precautionary work was prescribed:

- remove buckled and significantly damaged panels to an off-site shop for restoration
- repair all glass cracks on-site
- reestablish all ties to support bars
- provide exterior protection to windows adjacent to construction.

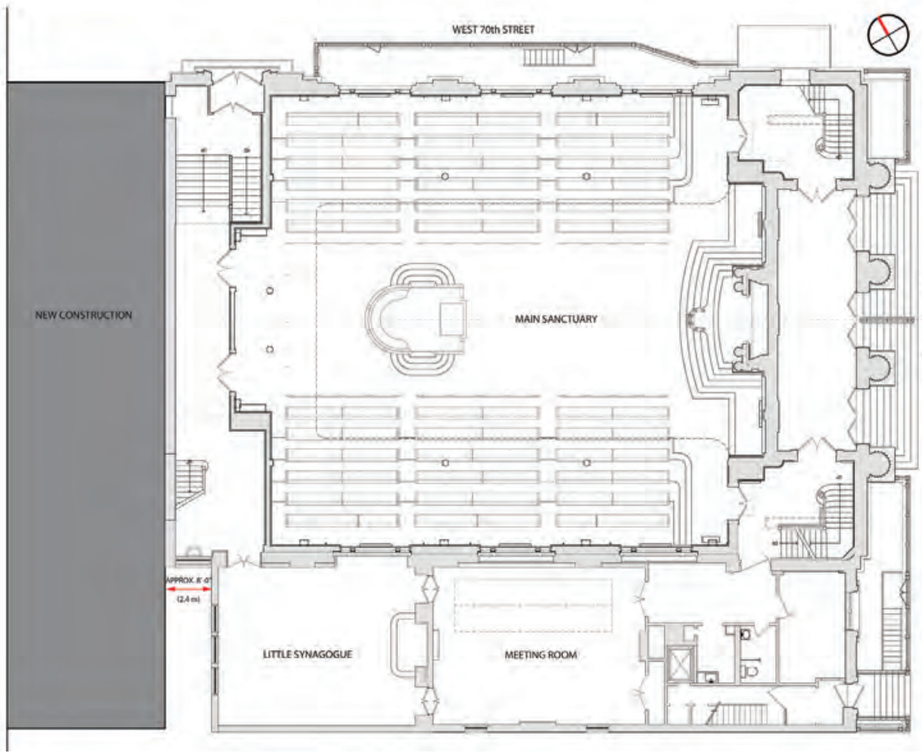


Fig. 4. First-floor plan, 2014. The new construction, which replaced the community house, is approximately 8 feet (2.4 m) distant from the west windows of the Little Synagogue. Drawing by PBDW Architects, 2014.

Work on the first three items was carried out by Mary Clerkin Higgins, who had undertaken the previous restoration work. The contractor for the project installed exterior plywood protection outside of the Little Synagogue, which was directly adjacent to the demolition (Fig. 4).

BCA had advanced various measures to protect the windows from construction vibrations, but all involved physical interventions that would have obscured or removed the windows. These measures included:

- removing the windows
- reducing the amount the windows can vibrate
- placing cushioning material against the glass
- stiffening the support bars.

These options would have had a significant negative effect on the worship experience or would have required invasive bracing. Installation of cushioning material against the glass would also have required measures to prevent moisture from penetrating the interface between the cushioning material and the glass.

An alternative approach was to ensure that the vibrations reaching the windows would not be a type to cause damage. Therefore, the best protection would be to eliminate agents of harm—in this case, monitoring the vibrations and stopping work if they exceeded a predetermined threshold. This approach was adopted, taking the following criteria into account:

- The windows were in good condition.
- Demolition would be performed without highly concussive equipment (no “wrecking balls”).
- Foundation piles for the new building would be augured, not driven.

In general, the construction operations were not expected to generate high-amplitude vibrations that would be transmitted to the windows. Having decided to monitor the vibrations on

Table 1. Previously Established Vibration Limits for Historic Buildings.

Source	Maximum PPV (in/sec)	Maximum PPV (mm/sec)
New York City *Technical Policy and Procedure Notice #10/88*, buildings	0.5	13
French Standard, buildings	0.3 (hard soil) 0.1 (soft soil, >0.2 Hz)	7.6 (hard soil) 2.5 (soft soil, >0.2 Hz)
USSR, buildings	0.4 (frequent) 1.2 (occasional)	10 (frequent) 30 (occasional)
Johnson and Hannen[3]	0.1–0.5 (historic buildings) 0.1 (art objects)	2.5–13 (historic buildings) 2.5 (art objects)

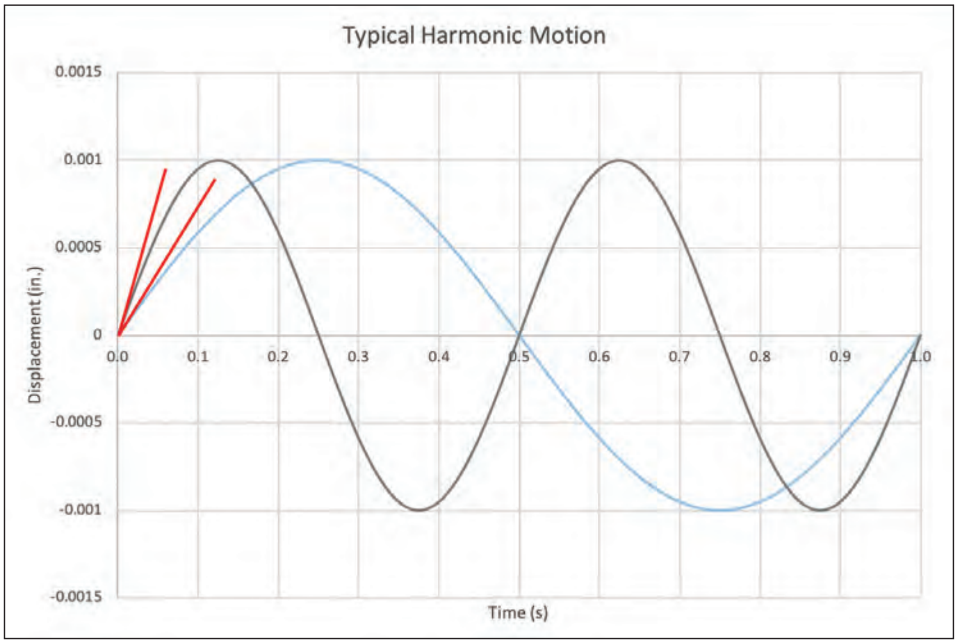


Fig. 5. Chart showing typical harmonic motion; displacement (inches) versus time (seconds). Courtesy of ANA.

the windows in lieu of physical intervention, the next step was to determine the threshold values. Limits of peak particle velocity (PPV) for buildings have been established by many countries, with a broad range of values (Table 1). Studies performed by the United States Bureau of Mines (USBM RI8507) that examined damage to buildings from blasting determined that "threshold damage" did not occur at PPV of less than 0.5 in/sec (13 mm/sec).[4]

A literature search produced only one suggested PPV for stained glass: 0.2 in/sec (5 mm/sec).[5] In the absence of data supporting that value and given the limited time before commencement of construction, BCA decided to adopt the value for maximum PPV but added a criterion for lateral displacement. Stained-glass windows are assemblies of small pieces of relatively rigid glass set in flexible lead cames so that they can tolerate a small amount of instantaneous deflections before metal fatigue becomes a factor. Since the windows deflected 0.125 inches (3 mm) under light finger pressure, it was decided to set a displacement threshold of half that. The CPP accordingly had the following values:

- PPV: alarm at 0.15 in/sec (3.8 mm/sec); stop work at 0.2 in/sec (5 mm/sec)
- Displacement: alarm at 0.047 inches (1.2 mm); stop work at 0.062 inches (1.6 mm).

The request for proposals for instituting the monitoring program was issued with the above limits, calling for the vibration and displacement monitors to be mounted directly on the windows. Demolition was scheduled to begin within a month of the call for proposals. When the companies that had bid on the vibration monitoring of the building itself were unable to provide the requested system in the short time frame, Atkinson-Noland & Associates (ANA), an engineering firm with extensive experience in non-destructive evaluation and monitoring, was retained by the owner to design and implement the system.

The nature of vibrations informed the development of the system. The data plot shown in Figure 5 indicates the displacement of a particle over time as vibration moves through the ground. The amplitude of the wave is the displacement. Vibrations are harmonic (i.e., cyclic). In this example, the frequencies are 1 Hertz (Hz) = 1 cycle per second (blue line) and 2 Hz = 2 cycles per second (gray line). The slope of the displacement versus time curve is velocity, which is greatest at zero displacement (red lines) and zero at the point of maximum displacement (motion reversal).

Generally, higher frequencies have a larger allowable PPV because they are of shorter duration. Most construction vibrations are in the range of 1 to 200 Hz. The background PPV at Congrega-

Fig. 6. Geophone mounted on a vertical stabilizing bar with custom clamps. Photograph by ANA, 2015.

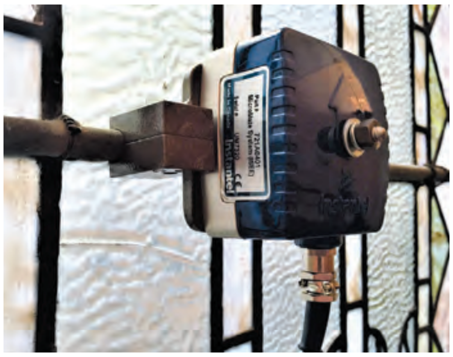


Fig. 7. Geophone mounted on a saddle bar with a custom clamp. Photograph by ANA, 2015.

tion Shearith Israel was determined to be 0.01 in/sec (0.25 mm/sec), mostly from the subway under the street directly in front of the building. Those vibrations can be felt by people in the building but have no discernable effect on the building or its contents.

ANA developed a monitoring installation that incorporates a series of triaxial geophones mounted with custom-fabricated clamps on the vertical stabilization bars at mid-height or on saddle bars where no vertical bars exist (Figs. 6 and 7). The geophones were set up to measure vibration-related velocity. Custom software was developed to calculate displacement from the vibration data. The geophones were of relatively low mass so as to have a minimal effect on the vibrational response of the windows (Fig. 8). They were connected to a data logger that provides continuous monitoring of data, which is transmitted to a dedicated website via a cell-phone modem. Battery backup kept the system running in the event of power failure.

After the initial installation but before demolition commenced, extremely high PPV values (>2 in/sec, 50 mm/sec) were recorded in the Little Synagogue every morning. Observation determined that the pivoting windows were opened before the morning service and then closed with enough force to retract the spring-loaded catch (Fig. 9). Similar high vibrations were recorded on windows in the main sanctuary space on some warm afternoons, attributable to the same factors.

On Saturday mornings, a series of triggering vibrations was recorded in the women's restroom. Investigation determined that the exhaust fan created negative pressure in the room, and every time the door was opened, the inrushing air caused the windows to vibrate. The room is generally used only during services on Saturday.

The system was originally configured to trigger and send a series of alarm emails if the measured PPV exceeded the thresholds, but adjustments were made to accommodate the effects of day-to-day use of the building on the monitoring system. The triggering event was changed from PPV to displacement. In addition, triggering events in the windows in the Little Synagogue were programmed not to send alarm emails if they occurred between 8:00 a.m. and 9:00 a.m.

After these adjustments, triggering events were recorded infrequently. Although the PPV thresholds were often exceeded, displacements were usually very low. Afternoon events were usually the result of closing windows forcefully (Fig. 10). Some of the other events occurred late at night, and most of those events corresponded to high winds as recorded by the National Weather Service at its nearby station in Central Park. Some of the large deflections were recorded on the tall windows with protective glazing on the exterior, indicating that the glazing did not protect the stained-glass windows from deflection caused by wind pressure. Vents in such glazing systems are designed to allow air to circulate in order to curtail condensation, but in this instance, they were not adequate to prevent the transmission of instantaneous loads, similar to what occurs in a double-skin drum.

The results of installing the monitoring system were positive. The system confirmed that the windows were not damaged by vibrations from construction operations. After the completion of demolition, all windows were surveyed for cracks, comparing the visible cracks to those recorded on the annotated and documentary photographs. Only one new crack was detected, adjacent to an operable panel at which several threshold events were recorded. Because of the damage sustained by the windows as a result of closing the operable panels, a new system of latching is being developed that does not require impact force.

This project demonstrated that intrusive actions are not always necessary to protect delicate building assemblies like stained-glass windows from the vibrations generated by construction operations. During a hiatus in construction, the monitoring system remained in place and recorded the vibrations experienced by the windows from everyday events. The system demonstrated that such vibrations often exceeded those generated

by construction operations. The threshold values for PPV and displacement used in this project prevented damage to the windows, but further study is necessary to establish tolerable displacement values for stained-glass windows in both good and poor condition. Acceptable PPV limits can be established from those values for a range of frequencies. One avenue of study would be to monitor the vibrations of stained-glass windows in a space that has a large conventional organ, especially when subject to the lower pedal tones. Other avenues should also be pursued in this effort.

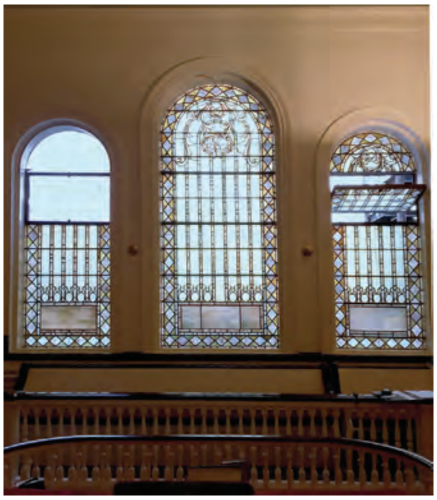
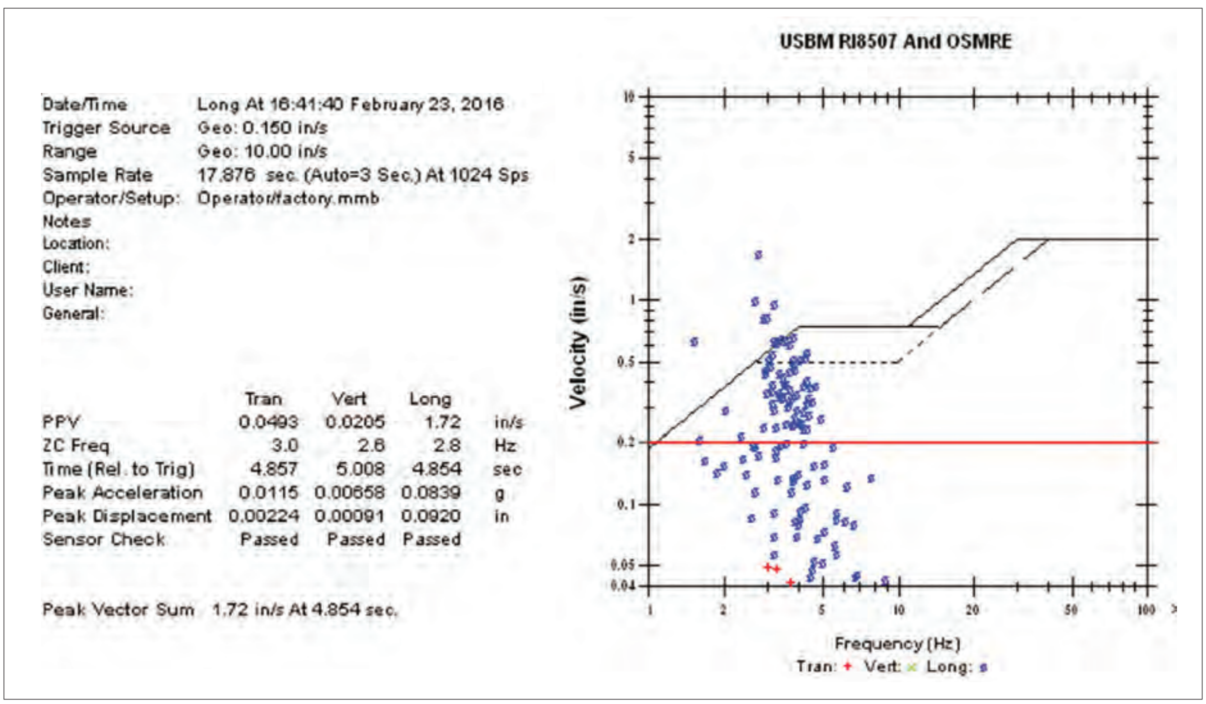


Fig. 8. Sanctuary with east windows removed and geophones in place (black arrows). Photograph by ANA, 2015.

Fig. 9. Open pivot window, Little Synagogue. Damaged panels in the left window were removed for repair in a shop. The construction area is directly behind these windows. Photograph by ANA, 2015.

Fig. 10. Excerpt from a data sheet from a recorded event, beginning 0.25 seconds before trigger. The red line in the graph shows the threshold. The event occurred at 4:40 p.m. on a Sunday afternoon, with displacement of 0.092 inches (2.3 mm) above the threshold value of 0.062 inches (1.6 mm). Maximum PPV of 1.72 in/sec (44 mm/sec) exceeded threshold value of 0.2 in/sec (5 mm/sec) by a factor of more than 8. Courtesy of BDI.



Acknowledgment

This article is dedicated to the memory of Dean Koga, who was a principal investigator and author of this paper before he passed away in 2019.

Dean Koga *(1950–2019), former president of the Association for Preservation Technology, was technical director at Building Conservation Associates, Inc., from 1994 to 2016. He held a bachelor's of science degree in chemistry and was a licensed architect.*

Erica Morasset *directs the Detroit office of Building Conservation Associates, Inc. A senior architectural conservator with 12 years of experience working on heritage buildings, she holds an undergraduate degree in chemistry and an M.S. degree in historic preservation from Columbia University. She can be reached at emorasset@bcausa.com.*

Raymond Pepi *is a conservator trained at Columbia University and the president and founder of Building Conservation Associates, Inc. He can be reached at rpepi@bcausa.com.*

David Woodham *is vice president at Atkinson-Noland & Associates in Boulder, Colorado, a consulting engineering firm specializing in the evaluation and repair of existing structures. He can be reached at dwoodham@ana-usa.com.*

Notes

1. Cyrus Adler, Max Kohler, Cyrus Sulzberger, and D. Hermalin, "New York," in *The Jewish Encyclopedia: A Descriptive Record of the History, Religion, Literature, and Customs of the Jewish People from the Earliest Times to the Present Day*, ed. Isidore Singer (New York: Funk & Wagnalls, 1906), 259–261.

2. Irving Polsky, *Technical Policy and Procedure Notice #10/88* (New York: The City of New York, Dept. of Buildings, 1988), 1–5.

3. Arne P. Johnson and W. Robert Hannen, "Vibration Limits for Historic Buildings and Art Collections," *APT Bulletin: The Journal of Preservation Technology* 46, nos. 2–3 (2015): 66–74. Threshold damage is defined as opening of existing cracks and formation of hairline cracks in plaster and gypsum board and dislodging of loose objects.

4. David Siskind, Mark Stagg, John Kopp, and Charles Dowding, *Report of Investigations 8507: Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting* (Washington, D.C.: U.S. Dept. of Interior, U.S. Bureau of Mines, 1980).

5. Arne P. Johnson, W. Robert Hannen, and Frank Zuccari, "Vibration Control during Museum Construction Projects," *Journal of the American Institute for Conservation* 52, no. 1 (2013): 30–47.

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