

WINDOW SOUND PROOFING FOR CONSTRUCTION NOISE AT THE CENTRAL ARTERY/TUNNEL PROJECT

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INTRODUCTION

One of the many challenges facing the Central Artery / Tunnel (CA/T) Project is to allow construction to proceed 24-hours a day for perhaps 14 years while necessarily minimizing the associated noise impacts to the community. This paper will review the precipitating factors that led the CA/T Project to develop and implement an acoustical window treatment program for qualifying residences and commercial businesses in close proximity to ongoing construction operations, and will detail the management, performance expectations, costs, and lessons learned of what turned out to be a very successful and well received adjunct to the Project's Noise Control Program [1].

WINDOW PROGRAM GENESIS

Since construction of this mega-project (estimated to cost \$10.8 billion) began in 1991, the CA/T Noise Control Program has incorporated many innovative construction noise control technologies, and will continue to do so through the completion of the Project scheduled for late 2004. One of the most cost-effective and successful noise control measures has been the systematic provision of acoustical window treatments for qualifying residential and commercial properties.

Originally it was hoped that construction noise could be successfully mitigated at the source and along the pathway with quieter equipment and the use of noise barriers. However, the vast extent of the construction activities combined with the fact that upper-story residential buildings did not benefit from noise barriers meant that additional noise control measures needed to be found. Thus, in late 1996 the Project began seriously considering acoustical window treatments as an adjunct to the source and pathway noise control measures already committed, and began a pilot program by treating select residential units. The Project was also able to learn valuable lessons from the Massachusetts Port Authority (Massport) through their long-time and successful residential sound insulation program sponsored by the Federal Aviation Agency (FAA) for eligible residences surrounding Boston's Logan International Airport.

In 1997, CA/T Project Management, working in conjunction with City of Boston (City) and Federal Highway Administration (FHWA) officials, developed an Off-Site Noise Mitigation Policy [2] which would reactively provide acoustical window treatments for qualifying abutting residences that had previously complained about construction noise and that met specific eligibility criteria. In 1998, the Project decided to expand the policy with a more pro-active window treatment program approach and developed a Residential Window Sound Insulation Program (Contract C30A1). Computer-based models were used to determine potential construction noise impact zones that were predicted to exceed CA/T Construction Noise Control Specification 721.560 [3] noise limits. A preliminary architectural and land-use survey determined that approximately 400 windows warranted treatment at an estimated cost of some \$500,000. In addition, many of the identified windows were subject to Historic Agency restrictions.

Depending on the conditions of existing prime windows, an array of treatment options are available which consist of (1) full replacement windows, (2) interior or exterior storm window sashes, or (3) clear vinyl interior curtains for commercial windows. The desired goal for window sound proofing is to achieve a Sound

Transmission Class (STC) [4] rating of 39 or greater, and an “incremental” improvement of at least 10 dBA in the noise reduction capabilities through the treated window system. To ensure these goals are being met, the Project purchases window materials from vendors who can demonstrate independent accredited acoustical laboratory test results supporting their claims for STC ratings. Moreover, the Project also performs its own “before” and “after” outside-to-inside noise reduction measurements to ensure the treated windows are meeting the desired performance goals.

With newly treated windows, residents and business owners immediately notice the improvement in their interior noise environment, and have sent many testimonial letters praising the Project’s efforts. The number of nighttime noise complaints have declined with the advent of the acoustical window program despite construction activities ramping-up towards peak construction schedule. But most importantly, the Project has been allowed to progress its work while avoiding inflicting significant noise-hardship to the public which can, and has, led to threats of delaying Project milestones.

OFF-SITE NOISE MITIGATION POLICY

Whereas construction of the CA/T Project potentially represents years of community noise impact, the Project has developed an Off-Site Noise Mitigation Policy through which an abutting resident or business owner can apply for window treatment considerations. The policy also is the basis by which CA/T Acoustical Engineers can recommend residential window treatments where construction noise impacts are anticipated and alternative noise mitigation methods are not feasible or cost-effective. The policy was cooperatively developed through the CA/T Project’s Noise Panel; a panel comprised of Project environmental, construction, and legal staff, Massachusetts Department of Environmental Protection staff, City of Boston traffic and environmental staff, and contributing Federal Highway Administration representatives.

The Off-Site Noise Mitigation Policy describes criteria against which applicants are evaluated on a case-by-case basis to determine if the Project will provide window treatments for construction noise mitigation purposes. In brief, the policy states that to be eligible for acoustical window treatments, the following conditions must apply:

- Construction activities adjacent to the property must be expected to continue for several months.
- Noise must not be adequately mitigated by other (source, path) control methods.
- The property must be in close proximity to the construction work (within about 300 ft).
- The building must be free of defects that could otherwise facilitate noise infiltration.
- The applicant must be a legal resident with an occupancy permit.
- Construction noise levels at the property must be exceeding the Project’s noise limits [3].
- Situations must involve health condition, hardship, or severe impact.
- The resident must be subjected to nighttime (10 PM to 7 AM) construction noise.
- The residential treatments are limited to treating bedrooms windows only.
- There must be a written Right-of-Entry Agreement signed by the owner and tenant to authorize the work.
- Cost expectations not to exceed \$800 per interior storm sash and \$2,500 per replacement window.
- The CA/T Noise Panel must approve beforehand the treatment and associated costs.

PERFORMANCE REQUIREMENTS

Acoustical window treatments to improve the noise reduction capabilities of residential window openings represents a proven successful means to implement receptor noise control. In general, window openings are the weak link in a structure’s external facade allowing noise infiltration into the building. When properly specified and installed, window treatments can provide for a significantly quieter interior noise environment. In general, window treatments are most cost-effective when a relatively few or widely scattered number of receptors require noise mitigation. Window treatments have the added attraction of reducing all city noise contributions such as from traffic and aircraft in addition to reducing construction noise. In this manner, the occupants tolerance of exterior construction noise can be increased.

After consideration, the CA/T Project developed a window treatment cost-benefit index, known internally

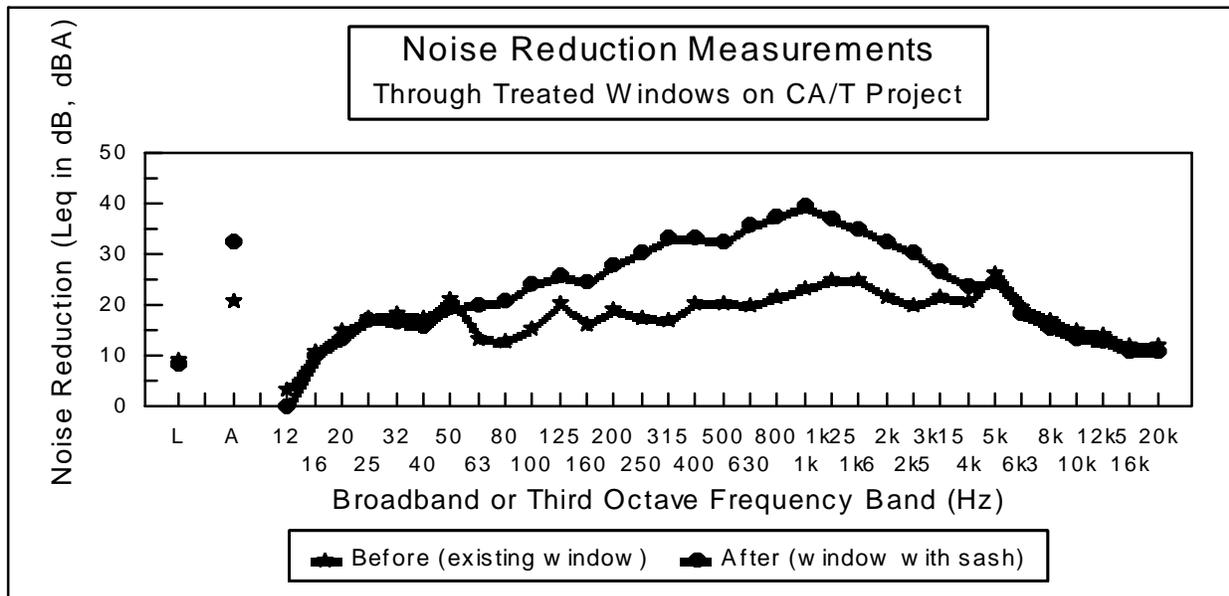
as the “windex”. The performance aspect requires a treated window to achieve an *incremental* noise reduction improvement of 10 dBA and a resulting *overall* outside-to-inside noise reduction of 35 dBA. These goals were based on the proven performance of other State programs, and should yield interior noise conditions subjectively perceived as about half the original (unmitigated) noise condition. Such an overall noise reduction requirement can in general be achieved with a treated window system capable of meeting a Sound Transmission Class (STC) of 39 or greater as per ASTM Test Method E90 based on typical construction noise composite spectra.

Several forms of acoustical window treatments are available, each with pros and cons as follows:

- *Full replacement acoustical windows* - double or triple pane glass, excellent noise reduction, but expensive.
- *Interior storm sash* - simple to install, least costly, good noise reduction, no historic restrictions.
- *Exterior storm sash* - inexpensive, marginal additional noise reduction, but historically limited.
- *Temporary interior clear vinyl curtains* - simple and quick, inexpensive, but somewhat unattractive.

When the selected acoustical window treatment is suitably performed, the resulting outside-to-inside noise reduction improvement can be dramatic, and can be perceived immediately by inhabitants as being about half as loud as the untreated condition. To illustrate, the following noise measurements were collected by CA/T Project staff to document the “before” and “after” conditions in this particular residential apartment space.

In this case, time averaged outside-to-inside noise measurements performed prior to treating the windows produced a noise reduction reading of only about 21 dBA. However, with the provision of an interior storm sash



and a very beneficial air gap of some 12 inches between the original window and the new interior sash, an improvement of some 11 dBA was realized through the treated window system which produced a noise reduction reading of about 32 dBA. Moreover, the frequency range which saw the largest increase in noise reduction were the important mid-frequency bands (of say 63 Hz up to 4 kHz) within which construction equipment produces significant noise emissions and human listeners are most sensitive.

The recommended type of window treatment for a given receptor must be evaluated on an individual basis. If the existing windows and frames are in decent physical condition and if the window frame depth will allow the necessary air space (of 2¼ inches minimum), then the most cost-effective treatment involves insertion of interior storm sashes. If, however, an existing window or frame is in disrepair, then a full replacement acoustic window may be warranted. Timing and logistic issues that may challenge a window treatment program include: (1) legal concerns, (2) labor agreements, (3) historic preservation issues, (4) procurement schedules, (5) staffing

requirements, (6) cost implications, (7) contractor scheduling, and (8) correspondence with eligible recipients. In light of these issues, a project must develop a window treatment eligibility criteria such as the Off-Site Noise Mitigation Policy which evaluates the need and justifies window treatments on a case-by-case basis.

WINDOW TREATMENT CONTRACT C30A1

In 1998, the Project elected to extend the heretofore reactive acoustical window program into a more pro-active program due in large part to the success of the reactive window program and the expectation that more intense construction schedules were forthcoming. Consequently, the Project formulated and put out for public bid the C30A1 Contract - Residential Window Sound Insulation Program. The intent and performance goals for acoustical window treatments in the proactive C30A1 Contract are the same as described above for the reactive Off-Site Noise Mitigation Policy.

Contract Formation: The Scope-of-Work for the C30A1 Contract had to be set up in accordance with the Massachusetts Highway Department (MHD) Standard Specification for Highways and Bridges. Therefore, this contract required Special Provisions that were specifically tailored to the window sound proofing program. The work included providing labor, using personnel skilled and experienced in installing acoustical window units, window sashes, storm windows, and historic window replacement per Massachusetts Historic Commission (MHC) and Boston Landmarks Commission (BLC) requirements.

A task force was set up within the Project that consisted of an Architect who was to be the Project Engineer, an Environmental Engineer with acoustical expertise, a Contract Manager, a Lawyer, a Community Liaison, an Estimator, a Scheduler, and a Resident Engineer who would be the Authorized Representative for MHD during the construction phase.

The Environmental Services Group of the CA/T Project developed a construction noise model that indicated geographic zones of potential construction noise impact. Thirty buildings consisting of approximately 100 dwelling units were identified. The MHD Right-of-Way Division scheduled site visits. An Acoustical Engineer accompanied by an Architect performed an assessment for the types of window treatments required to meet the acoustic performance goal (see above) that had been established by the CA/T Project. Approximately 400 windows, the vast majority of which being bedroom windows, were identified for various types of treatments.

Specifications were prepared by the Project Engineer with input by the Acoustical Engineer. Since the buildings were either historic or in a historic district, special attention had to be considered in how the windows would be treated to meet the required noise reduction while maintaining the historic appearance as well. In addition, specifications had to be prepared to address the removal and disposal of windows that may contain asbestos and/or lead paint. An office estimate of approximately \$500,000 was prepared in-house by Project Estimators, and the contract was publicly advertised for bid on 2/10/98.

Contractor Selection: Massachusetts General Laws (MGL) required that any contract greater than \$25,000 had to be advertised under MGL Chapter 149. All candidate contractors had to have been pre-qualified for the installation of windows in historic buildings. A pre-bid conference attended by six interested contractors was held to answer any questions on the contract. Four pre-qualified General Contractors eventually submitted bids, ranging from \$296,000 to over one million dollars. The contract was awarded to the lowest qualified bidder, GVW Incorporated. Notice-to-Proceed was issued to the contractor on 3/4/98.

WINDOW TREATMENT OPTIONS

Depending on case-specific necessities, the CA/T Project had a variety of acoustical window treatment options available through the C30A1 Contract, which included:

- *Full replacement* with an acoustical window that has an STC greater than 39. This type of window was a vinyl framed insulated double hung or sliding composite window which includes an attached aluminum double hung storm window with a 2" air space between the prime and the storm window.
- *Full replacement* of insulated aluminum or wood windows with an STC greater than 32. In addition an interior

storm sash with a STC greater than 27 would be installed on the inside of the prime window with a 2¼" minimum air space.

- *Interior or exterior storm sashes* with an STC of 27 or greater. These windows could be either aluminum double hung or vinyl frame fixed. This method of treatment would be used if the existing prime windows had a minimum of ½" insulated glass and windows were in good physical condition. The storm windows had to have a 2¼" minimum air space between the prime and new storm windows.
- *Vinyl transparent curtains* with an STC of 26 or greater were also used in commercial office space. The vinyl material had to have a weight of at least one lbs/sq. ft. and be 160 mils in thickness, and were fastened on the inside casings of the existing prime window using grommets and Velcro strip edges.

APPROVALS AND INSTALLATION

The process of gaining necessary approvals and then carrying-out the actual window treatment installation was a time consuming challenge. Early in the C30A1 Contract this entire process could take up to six months, however as the Project and the window contractor became more efficient and familiar with the requirements, the process was able to be completed in as few as two months. In general, the approvals and installation process consisted of the following steps.

1. The Authorized Representative prepares a Window Sound Insulation Agreement which includes a Right-of-Entry letter and description of the proposed treatment. The Community Liaison acquires owner/tenant signatures.
2. The Authorized Representative prepares and forwards a *task order* to the contractor identifying location, window treatment, estimated quantities, and applicable contract specifications. Changes necessary to customize for the location are negotiated by the Authorized Representative and coordinated with the Historic Resources Coordinator and the Architect.
3. The Community Liaison arranges for pre-construction evaluation coordinated by the Authorized Representative to include "before" condition noise measurements, video taping, and final window size measurements.
4. The Contractor orders the window treatments, which typically take 6-8 weeks for delivery.
5. The Authorized Representative arranges for window installation. The Contractor installs the window treatments, supervised by the Authorized Representative/Resident Engineer, who determines compliance with contract specifications and shop drawings in coordination with the Historic Resources Coordinator and Architect.
6. The Authorized Representative arranges access for post-construction evaluation that includes video taping and "after" noise measurements. The Authorized Representative coordinates resolution of claims associated with the work and documents final quantities on the original task order.
7. The Community Liaison acquires sign-off on the Right-of-Entry Agreement by the owner/tenant. The Authorized Representative approves payment to the contractor.

WINDOW PROGRAM RESULTS

As of July 1999, approximately 380 windows have been installed in 22 buildings along the CA/T Project alignment via the C30A1 window treatment contract. While the contract is still open and active, it is in the process of winding down and closing out its original scope, with completion expected by the end of 1999.

To date, approximately \$270,000 has been invoiced to the CA/T Project by the window contractor. Average window sound proofing treatment costs for a typical window of about 15 sq.ft. are as follows:

Full replacement acoustical window:	\$1,200 per window
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Full replacement metal/wood with interior storm:	\$1,600 per window
Interior or exterior storm window (sash):	\$500 per sash
Vinyl transparent curtains:	\$250 per curtain

LESSONS LEARNED

The proactive C30A1 Window Treatment Program and the reactive Off-Site Noise Mitigation Policy remain key ingredients in the CA/T Project's Noise Control Program to facilitate 24-hour ongoing construction operations in densely developed residential and commercial areas. The window treatments have been very well received by the public and the press, and are relatively inexpensive when compared to the costs involved with shutting down or delaying construction progress. Valuable lessons learned to date with the formulation and implementation of this window treatment program include:

- A policy, such as the Off-Site Noise Mitigation Policy, that clearly defines the purpose and scope is required before pursuing an acoustical window treatment program. The policy should include eligibility criteria, geographic limits, treatment options, and cost limitations. The policy should be developed with cooperative input from all interested parties (i.e. project and municipality) and should be applied consistently throughout the project. The policy should remain flexible enough to accommodate changes encountered as construction progresses.
- The CA/T Project retained in-house managerial control over its window treatment contract. This was particularly important and useful because Project Managers had to answer to property owners and City officials that were disturbed by excessive construction noise.
- When acoustical treatments are properly performed on windows, the noise reduction improvement provided by the treated windows were immediately noticeable to property owners. Before and after noise measurements revealed that treated windows actualized a noise reduction increase of 5 to 10 dBA.
- Interior storm sashes are the most attractive form of acoustic window treatment to the Project because they are relatively inexpensive, easy to install, minimize disruption for the property owner, avoid the need to contend with asbestos or lead paint issues, and are acceptable to Historic Agencies.
- It was discovered that the weight of large window sashes were too heavy for some elderly occupants to raise and lower, and were difficult to remove for cleaning. An interior storm sash that operated with balanced sashes and that could tilt in for ease of cleaning was found to be the solution.
- The contract required the contractor to provide shop drawings for the existing and proposed window treatment to be submitted for approval by the Historic Agencies. The preparation of shop drawings was later subcontracted to an Architectural firm that was more capable of providing these details.
- The window treatment contract should be managed by a full-time Resident Engineer with a background in construction, noise control, and contracts administration.
- The window treatment program should be scheduled such that the contractor has been selected, given Notice-to-Proceed, and has substantially completed eligible window treatments prior to noisy construction activities commencing.

References

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