

# Construction noise control program and mitigation strategy at the Central Artery/Tunnel Project

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One of the biggest challenges facing urban roadway and tunneling construction projects today is the need to mitigate associated environmental noise impacts. This article presents an overview of the Central Artery/Tunnel (CA/T) Project's noise control program and strategy to control this politically-charged issue. It has been demonstrated that failing to adequately control a project's "physical noise" can lead to the generation of more "political noise" than project managers may be able to handle. The CA/T Project, otherwise known as the "Big Dig", is the most ambitious and grandest-scale urban construction project ever undertaken in the United States. Construction in close proximity to thousands of residences and businesses may take 12 years to complete and cost upwards of \$13.6 billion. Broadly stated, the challenge facing the project's noise control program is to successfully control construction noise to avoid posing a hardship on abutting communities, while supporting construction milestones and ensuring environmental noise commitments contained in the Project's Environmental Impact Report are fulfilled. In general, the solution is a willingness to use any and all reasonable and feasible noise control methods to mitigate construction noise at the source, along the intervening pathway, or at the receptor locations. While cost estimates for the entire 18-year noise control program (design and construction) approach \$17 million, this figure is only 0.13% of the CA/T Project's total construction cost. The CA/T Project's noise control success to date starts with unambiguous "command support" from project managers. The project has made it publicly clear that noise control is highly regarded. Fair noise-related policies and specifications have been developed which balance the community's needs for peace and quiet with the project's needs to advance the work. The cornerstone of the project's noise control program is the Construction Noise Control Specification 721.560; the most comprehensive specification of its kind in the United States. The Noise Spec sets noise limits for the contractor, describes required submittals, contains contract-specific noise mitigation commitments, and provides guidance on source, pathway, and receptor noise control options. The Noise Spec's intent is to address noise pro-actively whenever possible; to anticipate and avoid creating undue noisy conditions, but also to allow proper reaction to control noisy conditions without sustaining costly claims from the contractors. With these available noise control measures, established policies and specifications, support from project officials, open dialog with the affected community, and due diligence, noise from this and other large-scale urban construction projects can be managed successfully. The lessons learned from this precedent setting construction noise control effort should be useful to many other future projects. © 2000 Institute of Noise Control Engineering.

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## 1. NOISE CONTROL CHALLENGE

The noise control challenge is great. The CA/T Project in Boston is the largest and most complex infrastructure construction project in the United States. Taking nearly a decade to define an acceptable scope to lobby Congress' support and 6 years to design, the project is now approaching the midway point of its estimated 12 year construction process. With its eventual completion in late 2004, the infamous Boston traffic bottle neck on Interstate Highways I-93 and I-90 will be alleviated, opening up the city and the entire New England corridor to normal flowing traffic. A new tunnel under Boston Harbor will better access Logan International Airport, and a new cable-stay bridge will span the Charles River. In addition to essentially doubling Boston's highway capacity, the project will also modernize Boston's underground utilities and prepare the city for positive growth into the next millennium.

Construction over the 7.5 linear mile project takes place 24-hours a day in various locations throughout the city. Construction equipment can operate in very close proximity to thousands of residential and commercial abutters, in some cases as close as 10 feet away. Hundreds of pieces of equipment can be found operating at any time project-wide. The full gambit of equipment types are in use such as cranes, slurry trenching machines, hydromills, hoe rams, pile drivers, jackhammers, dump trucks, concrete pumps and trucks, backhoes, loaders, excavators, vacuum trucks, concrete and chain saws, and gas and pneumatically powered hand tools. In total, some 13 million cu. yds. of excavate will be removed and almost 4 million cu. yds. of concrete will be placed.

The project's noise control mission is to support and maintain construction progress, while concurrently ensuring fulfillment of the project's noise-related environmental commitments. While some noise disturbance to abutting densely populated residential areas may be inevitable given the inherently noisy operations associated with such a massive

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construction project, the project has remained committed to control and minimize construction noise using all reasonable (i.e. cost implications) and feasible (i.e. physically achievable) means available.

In addition to managing the “physical acoustics” challenge, the project must also satisfactorily manage the “political acoustics” aspect of such a large-scale project.<sup>1,2</sup> The project must ensure that construction noise does not raise public ire which can then lead to significant public animosity and elevated pressure on the city’s elected officials and project managers. Failure to satisfactorily control construction noise can, and has, posed a real threat to the progress of such a project. However, with proper management and due diligence, construction noise can be satisfactorily controlled such that abutters do not suffer noise-related hardships, politicians remain in the good graces of the public, and project managers can continue to meet project milestones.

## **2. CA/T NOISE CONTROL PROGRAM RESPONSIBILITIES**

The project’s noise control program is considered an essential element to facilitate ongoing construction that could otherwise be hindered by distressed community groups and/or city officials. In general, the project’s noise control program is charged with the following responsibilities.

Developing the noise impact section of the Project’s Environmental Impact Report:<sup>3</sup>

- evaluating potential traffic and construction noise impacts Project-wide in accordance with applicable Federal (FHWA) and State noise guidelines

Developing the CA/T Construction Noise Control Specification 721.560 which:<sup>4</sup>

- establishes lot-line and equipment emission noise criteria limits
- defines operational and/or equipment restrictions
- requires submission of a suitable acoustical engineer; noise control and monitoring plans; collection of baseline and compliance noise data; submission of equipment noise certification tests; and design of noise mitigation measures as needed

Performing special noise studies and project-change impact analyses, such as:

- evaluating noise consequences through measurements and predictive modeling
- preparing noise sections for Notice of Project Change (NPC) regulatory filings

Overseeing contractor compliance with contract-specific noise limits by:

- performing short-term and long-term noise compliance monitoring
- providing a presence in the field during nighttime periods (Noise Patrol)
- ensuring that contractors are fulfilling their noise control plans
- being prepared to shut down otherwise unmitigatably noisy work at night

Providing technical and field support to construction managers by:

- responding to and supporting resident engineers to keep work progressing
  - documenting contractor noise compliance for QA purposes
- Presenting noise issues before the city and affected communities, such as:

- participating and contributing on the CA/T Project’s Noise Panel
- presenting specific construction operations and noise mitigation strategies to city officials and to the public at regular and special community meetings

Training field staff on noise issues, measurement, evaluation, and control through:

- presentation of the CA/T Noise Control Workshop to all field staff
- providing on-site mentoring and mitigation recommendations

Providing defensible technical advice in noise-related legal challenges, such as:

- preparing expert witnesses for supporting courtroom testimony
- defending the project’s position when challenged by abutters
- documenting reasons to avoid contractor claims for noise-related work stoppages

Developing noise mitigation programs and strategies for policy adoption, such as:

- developing area-specific noise mitigation measures (noise sheets)
- designing large-scale noise barrier/curtain systems
- developing and implementing an acoustical window treatment program
- developing noise-related policies (e.g. Off-Site Mitigation Policy)

## **3. NOISE CONTROL POLICY**

The success of the project’s noise control program owes much to the high level of “command support” afforded to the program. Project managers have shown through their deeds and actions that construction noise control will be held in very high regard throughout the project.

In order to reaffirm and provide a consistent noise-related message regarding the project’s policy on construction noise mitigation, a policy summary was promulgated throughout the project and distributed to the community.<sup>5</sup> This policy summarizes several key aspects of the project’s overall noise control program including: (1) a commitment statement to minimize noise impact on abutting residents while maintaining construction progress, (2) a summary of the project’s noise control specification criteria and components, (3) a willingness to develop area-specific noise mitigation strategies tailored to particular community needs and sensitivities, (4) an approach and criteria for deciding the appropriateness of mitigation measures, and (5) a commitment to provide qualified noise technicians in the field to oversee contractor compliance.

#### 4. CONSTRUCTION NOISE CRITERIA LIMITS

Developed to be consistent with the intent of the city of Boston's Noise Code,<sup>6</sup> the CA/T Project has adopted and refined the most comprehensive and stringent construction noise control specification 721.560 of any public works project in the country.<sup>4</sup> The specification contains both "relative" noise criteria limits at identified noise sensitive receptor locations, as well as "absolute" noise emission limits for any/all equipment used on site. These two criteria can be seen in Tables 1 and 2, respectively.

As shown in Table 1, the noise spec's lot-line criterion is primarily a relative criterion in which construction-induced L10 noise levels in general can not exceed baseline (pre-construction) L10 A-weighted noise levels by more than 5 dB at identified noise sensitive receptor locations. This decision followed a preliminary study of various noise criteria world-wide which convinced the CA/T Project that while an increase of 5 dB may be noticeable, it should not represent an unacceptable noise hardship condition.<sup>7</sup> L10 noise limits in the noise spec are intended to address and have in practice been shown to correlate well with more steady construction noise averaged over some time interval, of say 20 minute periods. Lmax noise limits also apply at the receptors' lot-lines and are intended to address loud impact-type noise events.

Baseline L10 noise levels must be established prior to construction operations in accordance with the noise spec which requires collection of at least two non-consecutive weekday 24-hour noise readings as well as one Sunday noise reading at specified noise receptor locations throughout the contract area. These baseline L10 noise readings are then reduced into daytime, evening, and nighttime average levels

and used to establish lot-line noise criteria limits by adding 3 or 5 dB, as applicable, or by defaulting to the higher absolute L10 limit option provided in the noise spec (see Table 1).

At this point in time, the project's noise group has assumed the responsibility of measuring baseline noise conditions in anticipation of new contract work. Formerly however, the contractors had to submit their own baseline noise measurements and corresponding noise spec criteria limits to the project for review and acceptance before construction work could begin.

As also shown in Table 1, noise receptors were selected throughout the project area to represent other similar-type receptors based on their proximity to proposed construction work. Additional receptors can be added to contracts as they are identified. Three types of receptor land uses are recognized: (1) Noise Sensitive Areas - involving nighttime land use such as residences, hotels, and hospitals, (2) Commercial Areas - such as businesses and office buildings, and (3) Industrial Areas - such as factories and large plants. The lot-line criteria limits are more stringent for residential receptors than for commercial or industrial receptors in lieu of the more sensitive nature of residential land use. In addition, there are different criteria limits depending on various times of day, with the most restrictive noise limits applied to the more sensitive nighttime period. Daytime is defined from 7:00 AM to 6:00 PM, evening is considered to be 6:00 PM to 10:00 PM, and nighttime is defined as 10:00 PM to 7:00 AM.

As shown in Table 2, contract specifications also contain an absolute noise criterion which is applied to generic classes of heavy equipment to limit their noise emissions. Equipment-specific A-weighted Lmax noise limits in dB evaluated at a

TABLE 1 - CA/T project lot-line construction noise criteria limits.<sup>4</sup>

Noise Receptor Locations and Land-Uses	Lot-Line Construction Noise Criteria Limits A-weighted in dB, RMS slow					
	Daytime (7 AM - 6 PM)		Evening (6 PM - 10 PM)		Nighttime (10 PM - 7 AM)	
	L10	Lmax	L10	Lmax	L10	Lmax
Noise-Sensitive Locations: (Residences, Institutions, Hotels, etc.)	75				Baseline + 5	
	or	85	Baseline + 5	85	(if Baseline < 70)	80
	Baseline + 5	90 (impact)			Baseline + 3	
	(which ever is louder)					
Commercial Areas: (Businesses, Offices, Stores, etc.)	80					
	or	None	None	None	None	None
	Baseline + 5					
Industrial Areas: (Factories, Plants, etc.)	85					
	or	None	None	None	None	None
	Baseline + 5					

Notes: L10 noise compliance readings are averaged over 20 minute intervals. Lmax noise compliance readings can occur instantaneously. Baseline noise conditions must be measured and established prior to construction work commencing in accordance with the Noise Spec which requires baseline noise readings over three 24-hour periods at each receptor lot-line location.

TABLE 2 - CA/T project construction equipment noise emission criteria limits (all levels are A-weighted).<sup>4</sup>

Equipment Description	Lmax Noise Limit at 50 ft, dB, slow	Is Equipment an Impact Device?	Acoustic Usage Factor
All other equipment > 5 HP	85	No	50 %
Auger Drill Rig	85	No	20 %
Backhoe	80	No	40 %
Bar Bender	80	No	20 %
Blasting	94	Yes	1 %
Boring Jack Power Unit	80	No	50 %
Chain Saw	85	No	20 %
Clam Shovel	93	Yes	20 %
Compactor (ground)	80	No	20 %
Compressor (air)	80	No	40 %
Concrete Batch Plant	83	No	15 %
Concrete Mixer Truck	85	No	40 %
Concrete Pump	82	No	20 %
Concrete Saw	90	No	20 %
Crane (mobile or stationary)	85	No	20 %
Dozer	85	No	40 %
Dump Truck	84	No	40 %
Excavator	85	No	40 %
Flat Bed Truck	84	No	40 %
Front End Loader	80	No	40 %
Generator (25 KVA or less)	70	No	50 %
Generator (more than 25 KVA)	82	No	50 %
Gradall	85	No	40 %
Grader	85	No	40 %
Horizontal Boring Hydraulic Jack	80	No	25 %
Hydra Break Ram	90	Yes	10 %
Impact Pile Driver (diesel or drop)	95	Yes	20 %
Insitu Soil Sampling Rig	84	No	20 %
Jackhammer	85	Yes	20 %
Mounted Impact Hammer (hoe ram)	90	Yes	20 %
Paver	85	No	50 %
Pickup Truck	55	No	40 %
Pneumatic Tools	85	No	50 %
Pumps	77	No	50 %
Rock Drill	85	No	20 %
Scraper	85	No	40 %
Slurry Plant	78	No	100 %
Slurry Trenching Machine	82	No	50 %
Soil Mix Drill Rig	80	No	50 %
Tractor	84	No	40 %
Vacuum Street Sweeper	80	No	10 %
Vibratory Concrete Mixer	80	No	20 %
Vibratory Pile Driver	95	No	20 %
Welder	73	No	40 %

Notes: "Impact" equipment is assumed to produce separate discernable sound pressure maxima.  
 "Acoustic Usage Factor" represents the percent of time that equipment is assumed to be running at full power while working on site

reference distance of 50 ft are defined in the noise spec. These emission limits are achievable but have been conservatively set as low as possible by the project in order to require equipment to be well maintained, and often times require some form of source noise control. Each and every piece of equipment must be pre-certified by the contractor's acoustical engineer to pass their respective 50-ft noise emission limit

before the equipment is allowed to work on site.

Thus, the contract specifications contain two types of noise criteria limits, relative lot-line limits and absolute equipment emissions limits, both of which must be complied with by the contractors at all times. Consequently, if measured or anticipated construction noise levels exceed the allowable noise criteria limits, then noise mitigation measures are

warranted and must be implemented prior to and maintained during associated work activities. Failure on the contractor's part to comply with these noise criteria limits can lead to the offensive work operations being shut-down until such time as adequate noise mitigation can be ensured.

At the project's discretion, Deficiency Reports can be issued and payments can and have been withheld from contractors who repeatedly cause noise complaints or work in violation of their noise spec limits. Also, the city of Boston's environmental inspectors can issue noise-related citations and fines against offending contractors, often times amounting to as much as \$25,000 per occurrence.

## 5. NOISE CONTROL STRATEGY AND METHODS

The CA/T Project follows a step-wise approach towards mitigation of construction noise to avoid adversely affecting abutting sensitive residential receptors. The expected noise reduction performance benefits of proposed mitigation measures must be weighed against cost implications. Noise mitigation measures are implemented only when justified based on careful consideration of all relevant technical, cost, and policy issues.

Source control is most highly prioritized because it is, in general, the most effective form of noise control by eliminating a noise source before it is allowed to emit offensive noise levels. Source controls which limit noise emissions or restrict allowable types or operating times of heavy equipment are also the easiest to oversee on a construction project. When source control measures by themselves are not sufficient to avoid noise impact, then path control measures are designed and implemented. Intervening pathways over which construction noise propagates to sensitive receptors can be effectively interrupted with noise barriers and/or curtains, providing care is taken to completely block the line-of-sight between the noise source and the affected receptors. However, there are numerous circumstances on the CA/T Project where source and path noise control measures are not feasible or sufficient. In these cases, receptor control measures such as window treatments are necessary. Because window openings are typically a building's weakest link for noise infiltration, acoustical window treatments can significantly reduce the outside-to-inside noise contribution. Depending on the numbers of affected residents, the configuration of work sites, and the proximity of nearby abutters, window treatments may be more cost-effective and viable than would be noise barriers or curtains. Also, the benefits of effective public outreach and participation can not be overstated as a form of receptor noise control. Working in partnership with the affected community greatly increases the community's tolerance to noise.

General examples of source, path, and receptor noise control measures routinely applied on the CA/T Project include the following:

### *Source Controls:*

- Time Constraints – prohibiting work during sensitive nighttime hours
- Scheduling – performing noisy work during less sensitive

time periods

- Equipment Restrictions – restricting the type of equipment used
- Emission Restrictions – specifying stringent noise emission limits
- Substitute Methods – using quieter methods/equipment when possible
- Exhaust Mufflers – ensuring equipment have quality mufflers installed
- Lubrication & Maintenance – well maintained equipment is quieter
- Reduced Power Operation – use only necessary size and power
- Limit Equipment On-Site – only have necessary equipment on-site
- Noise Compliance Monitoring – technician on site to ensure compliance
- Quieter Backup Alarms – manually-adjustable or ambient-sensitive types

### *Path Controls:*

- Noise Barriers – semi-permanent or portable wooden or concrete barriers
- Noise Curtains – flexible intervening curtain systems hung from supports
- Enclosures – encasing localized and stationary noise sources
- Increased Distance – perform noisy activities farther away from receptors

### *Receptor Controls:*

- Window Treatments – reinforcing the building's noise reduction ability
- Community Participation – open dialog to involve affected residents
- Noise Complaint Process – ability to log and respond to noise complaints
- Temporary Relocation – in extreme otherwise unmitigatable cases

## 6. NOISE CONTROL PLANS

In general, the selection of appropriate noise mitigation methods is first assessed and proposed by each construction contractor, working in conjunction with their acoustical engineer, as required in the noise spec. Whereas contractors are contractually obligated to comply with both the lot-line and equipment emission criteria limits, contractors must submit for review and approval updated noise control plans which detail the contractor's strategy and means to comply with contract-specific noise criteria limits. The noise control plan pro-actively evaluates anticipated construction noise consequences at all identified noise sensitive receptors within each contract area by: (1) identifying where and what type of construction equipment will be used during respective time periods, (2) predicting noise levels at receptor locations using accepted point-source-strength propagation algorithms\* contained in the noise spec, (3) comparing those predicted results against noise criteria limits, (4) if warranted, identifying proposed noise mitigation measures required to

ensure compliance, and (5) demonstrating the expected beneficial noise reduction affects in both a qualitative and quantitative manner.

\* Note: The primary equation used in predicting construction-induced L10 noise levels at receptor locations, when summed over all operating equipment, is as follows:

$$A\text{-weighted } L10 \text{ in dB} = L_{\max@50ft} - 20 \text{ LOG } (D/50) + 10 \text{ LOG } (U.F.\%/100) + 3 - IL_{bar}$$

Where:  $L_{\max@50ft}$  is the A-weighted emission limit for the equipment at 50 feet (see Table 2).

$D$  is the distance, in feet, between the equipment and the receptor.

$U.F.\%$  is a time averaging equipment usage factor, in percent (see Table 2).

$IL_{bar}$  is the A-weighted insertion loss of any intervening barriers, computed separately.

The +3 dB adjustment factor was empirically determined by examining the average difference between  $Leq$  and L10 noise levels over many hours of construction noise measurements.

In circumstances where the contractor's noise control plan proves inadequate in the field or communities press the project to further mitigate construction noise, the project will perform additional noise analyses in order to devise mutually acceptable noise mitigation strategies. Any proposed additional mitigation measures are developed to consistently apply the project's noise control policy.<sup>5</sup>

While the goal to minimize construction noise impact project-wide remains consistent, the means to achieve that goal may vary from contract-to-contract because of area-specific geographical conditions, types of construction work and equipment required, inherent noise reduction qualities of affected receptor structures, and the wishes of the affected community. The tailoring of noise mitigation measures involves assessment for technical performance, reasonability and feasibility, and cost/schedule implications. Any proposed mitigation measures must also be presented to the affected neighborhoods through community meetings.<sup>2</sup> The community has an opportunity to voice individual and collective opinions in response to project proposals. It remains an essential element in the project's noise control strategy to actively solicit community participation and to demonstrate flexibility to match ever-changing construction conditions. Once finalized, these contract-specific noise mitigation measures can be incorporated into the construction contracts and implemented.

## 7. MITIGATION PERFORMANCE REQUIREMENTS

Noise mitigation measures used on the CA/T Project are foremost intended to reduce construction-induced noise levels to comply with contract-specific noise criteria limits and/or to fulfill commitments incorporated in the Project Environmental Impact Report.<sup>3</sup> When more extensive mitigation measures are required, such as noise barriers/curtains or window treatments, then the project applies

performance requirements to the proposed mitigation to ensure that adequate noise reduction results will be realized. The technical performance requirement to justify the use of noise barriers/curtains and window treatments are explained in this section.

### A. Noise barriers/curtains

In general, noise barriers or curtains are cost-effective when they can provide perceptible noise reduction benefits to a relatively large number of sensitive receptors. Many practical considerations must be evaluated before a noise barrier/curtain can be deemed feasible. For example, to be effective the barrier/curtain must physically fit in the available space, must completely break the line-of-sight between the noise source and the receptors, must be free of degrading holes or gaps, and must not be flanked by nearby reflective surfaces. Noise barriers must be sizable enough to cover the entire noise source, and extend length-wise and vertically as far as feasibly possible to be most effective. If practical, noise barriers should be tall enough to provide noise reduction for the upper-most stories of nearby sensitive receptors, though this may not always be achievable with abutting multi-story buildings. Indeed the limiting factor for a noise barrier is not the component of noise transmitted through the material, but rather the amount of noise flanking around and over the barrier. In these cases, the barrier/curtain system must either be very tall or have some form of roofed enclosure to protect upper-story receptors. Other challenges involve placing a barrier across an active roadway. This can be done usually for short periods of time (such as nightly) providing the barrier is made in a portable fashion, such as built on movable bases or retracted out of the way when not needed.

The project's performance requirement for noise barriers/curtains requires a reduction in A-weighted construction noise levels at nearby receptor locations (insertion loss) of 10 dB. Such a design goal is appropriate because it represents a reasonable limit for the degree of noise reduction feasibly achievable in the field, and such a reduction is perceived by affected receptors as halving the loudness of the original unmitigated noise condition. When properly installed such that the barriers break the line-of-sight between the receptors and the equipment and are free of holes or gaps, a noise barrier system is capable of providing A-weighted noise insertion losses of some 10 to 15 dB. Even at upper-story receptor locations where the barriers just break the line-of-sight, barrier insertion losses of about 5 dB can be realized.

In order to specify such a performance requirement, the Project's Construction Noise Control Specification 721.560 contains sections devoted to the appropriate selection and use of noise barriers/curtains.<sup>4</sup> In the specification, a barrier/curtain must achieve a Sound Transmission Class (STC) of 30 or greater in accordance with ASTM Test Method E90,<sup>8</sup> and be constructed from a material having a surface density or at least 2 lbs/sq.ft. to ensure adequate transmission loss characteristics. In addition, to avoid objectionable noise reflections, the source side of the noise barrier/curtains must be lined with an acoustic absorption material meeting a Noise Reduction Coefficient (NRC) rating of 0.70 or greater in accordance with ASTM Test Method C423.<sup>9</sup>

## B. Acoustical window treatments

Acoustical window treatments to improve the noise reduction qualities of residential window openings represents a proven successful means to implement receptor noise control.<sup>10</sup> 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, particularly in multi-story buildings with upper-floors that may not benefit from typical noise barriers. 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 contribution such as traffic and aircraft noise in addition to reducing construction noise. In this manner, residents' tolerance of exterior construction noise is increased.

After much 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 A-weighted noise reduction improvement of 10 dB and a resulting overall outside-to-inside A-weighted noise reduction of 35 dB.<sup>11</sup> 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.<sup>8</sup>

Several forms of acoustical window treatments are available, and each have their pros and cons:

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

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 say 3 inches), 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 required. 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 criterion (i.e. Off-Site Mitigation Policy<sup>11</sup>) which evaluates the need and justifies window treatments on a case-by-case basis.

## C. Off-Site Mitigation Policy

Whereas construction of the CA/T Project potentially represents years of community noise impact, the project voluntarily developed an off-site mitigation policy through which abutting residents can apply for window treatment considerations.<sup>11</sup> Other sound proofing options such as new doors, enhanced wall and attic insulation, or air conditioning systems were determined not to be cost-justifiable given the substantial noise reduction benefit that treated windows can provide. 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 project's noise panel; a panel comprised of project environmental, construction, and legal staff, city of Boston traffic and environmental staff, Massachusetts Department of Environmental Protection staff, and representatives from the Federal Highway Administration.

The Off-site Mitigation Policy<sup>11</sup> describes criteria against which residential applicants are evaluated on a case-by-case basis to determine if the project will provide bedroom window treatments for construction noise mitigation purposes. In brief, the policy states that to be eligible for bedroom window treatments, the following conditions must apply:

- The resident must be subjected to ongoing nighttime construction noise for at least two months.
- Construction noise levels measured at the residence must exceed the project's noise spec limits.
- Noise must not be adequately mitigated by other (source, path) control methods.
- The resident must be in close proximity to the construction work (within about 300 ft, see \* below).
- The building must be free from defects that could otherwise facilitate noise infiltration.
- The applicant must be a legal resident with an occupancy permit.
- Situations must involve health condition, hardship, or severe impact (but not financial means).
- The treatment is limited to treating windows affecting bedrooms only.
- There must be a written right-of-entry signed by the resident to authorize the work.
- Cost expectations not to exceed \$800 per interior sash and \$2,500 per replacement window.
- The CA/T Noise Panel must approve beforehand the treatment and associated costs.

\*Note: "Close proximity" is neighborhood-specific depending on the background noise conditions and is defined as being within the so-called "critical distance", or the distance within which noise levels are predicted to potentially exceed Noise Spec limits given an assumed hypothetical mix of construction equipment.

## 8. CA/T NOISE CONTROL PROGRAM COSTS

An order of magnitude attempt to re-assemble past costs and estimate anticipated future costs associated with the entire

CA/T Noise Control Program has been prepared.<sup>1</sup> This cost estimate attempts to summarize cumulative noise-related costs from the start of the noise program in 1987 through to project completion in late 2004, disaggregated into four categories as follows:

- Direct Expenses
- Indirect Expenses
- Mitigation Costs
- Contractor Costs

As summarized in Table 3 below, **Direct Expense** estimates include the fully burdened costs of project noise staff, home office staff, and task orders to sub-consultants. Labor costs were included for noise-related work as far back as the preparation of the EIS/R,<sup>3</sup> and are extended to project completion based on current manpower expectations. **Indirect Expense** estimates include all noise-related equipment and measurement instrumentation, such as project noise monitors and computers. **Mitigation Cost** estimates include special, large-scale noise barrier/curtain systems, acoustical window treatments, and prorated portions of past noise-related legal settlements. **Contractor Cost** estimates include the cost for construction contractors to fulfill requirements contained in their respective Construction Noise Control Specification 721.560 and were detail-estimated on a contract-specific basis.<sup>4</sup>

To put Table 3 more in perspective, if the figure of \$16,958,000 was normalized annually for the 18 years over which the CA/T Noise Program will function during both design and construction, the annual costs for the noise program would amount to \$942,000 per year. For comparison, at this point in time (60% completion) the construction contractors are invoicing the project at a rate of about \$4 million per day. Moreover, if the costs for the noise program are compared to the overall CA/T Project anticipated total cost of \$13.6 billion, the noise program would represent only 0.13% of the total project cost. For comparison, other agencies and transportation projects have earmarked 2-to-3% of a project's overall costs towards noise abatement.

It should be noted that this cost estimate did not attempt to quantify the potential savings associated with the successful implementation of a coordinated noise program. The project's ability to progress with construction in a densely populated urban environment where noise-related issues threaten to

hinder project milestones must certainly constitute substantial savings and should not be under appreciated.

## 9. KEY LESSONS LEARNED

The CA/T Project has been called the largest construction laboratory in the world within which all forms of construction techniques and mitigation strategies can be developed and refined. Some of the more valuable noise control lessons learned to date include:<sup>1</sup>

- Project managers and sponsoring agencies must demonstrate through deeds and actions that construction noise control will be held in high regard throughout the duration of the project.
- While the means may vary from location-to-location, noise policy commitments and noise control goals must be consistently applied project-wide.
- A comprehensive and unambiguous noise specification is essential for managing the contractors on noise-related matters and for minimizing costly work-stoppage related claims.
- A relative noise criterion (Baseline L10 + 5 dB) is fair and allows for construction progress while avoiding noise hardship in the community; providing that adequate baseline noise levels are collected prior to work commencing.
- Noise control strategies must include source, pathway, and receiver control options and be flexible to accommodate different community needs as work conditions change.
- Noise barriers not only significantly reduce construction noise, but they also provide an extra benefit of "hiding" the noise producing sources, thus increasing abutters' tolerance.
- Acoustical window treatments are a very cost-effective means to reduce construction noise from entering a building. Moreover, noise control resources can be better targeted towards those receptors in most need of noise mitigation.
- A noise technician on site is able to pro-actively avoid many noisy situations and can respond to and evaluate noise complaints immediately. The noise technician should have the authority to shut down particularly noisy operations until acceptable mitigation is implemented.

TABLE 3 - CA/T noise control program cost estimate.

Noise Control Program Cost Category	Total Estimated Cost (1987-2004)
Direct Expenses:	\$5,326,000
Project Noise staff, Home-Office staff, and Sub-consultants	
Indirect Expenses:	\$102,000
Noise monitoring equipment and instrumentation	
Mitigation Costs:	\$6,109,000
Noise barriers/curtains, windows treatments, legal settlements	
Contractor Costs:	\$5,421,000
Contractors fulfillment of Noise Spec. 721.560 requirements	
Total =	\$16,958,000



- The greatest single source of noise complaints results from the use of loud backup alarms on vehicles working at night. The solution has involved requiring all project-related vehicles to be equipped with either manually-adjustable or ambient-sensitive backup alarms (which have built in feedback circuitry to automatically limit the alarm's noise output to only 5 to 10 dB above background noise). In general, these type alarms are about 20 dB (A-weighted) quieter (or 1/4 as loud) than standard alarms. In more contentious and sensitive residential areas, the CA/T Project has gone so far as to prohibit the use of audible backup alarms at night, thus requiring the contractor to use dedicated observers to ensure safe vehicle movements in accordance with OSHA requirements.
- The affected community must be actively involved and informed regarding noise producing operations and proposed noise mitigation measures. The project must be available via a 24-hour a day hotline to receive and act upon noise complaints.

Through these key measures and by consistently implementing the policies, specifications, and strategies of a comprehensive noise control program, construction noise can be successfully managed both physically and politically on a large-scale urban construction project.

## 10. REFERENCES

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