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PROACTIVE CONSTRUCTION NOISE CONTROL POLICIES DEVELOPED FOR THE CENTRAL ARTERY/TUNNEL PROJECT'S C17A6 CONTRACT

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INTRODUCTION

The Central Artery/Tunnel Project (The Big Dig) in Boston is the most ambitious urban construction project ever undertaken in the United States. One of the most politically-charged challenges that the project has had to successfully manage involves noise. Fortunately, lessons learned through almost 10 years of construction to date served well towards developing proactive noise mitigation policies for the project=s final remaining contract [1]. The C17A6 contract will finish about 2 miles of tunnels and surface roadways through downtown Boston, and will demolish and remove the existing elevated I-93 Artery. In preparation, project staff met as early as 1998 with design and environmental engineers, as well as community and City representatives in order to devise mutually acceptable policies towards mitigating C17A6-related noise. Comprehensive noise prediction studies were performed, candidate noise control options were developed, and costs were considered. Eventually, a series of noise mitigation measures, totaling about $3 million, were approved for inclusion in the C17A6 contract. These measures included equipment restrictions at night, noise barriers and curtain systems, acoustical window treatments, prohibition of backup alarms at night, and continued oversight with dedicated noise technicians. With these measures committed to the public, the C17A6 contract went out to bid in April 2001 at an estimated price of $440 million.

HISTORY AND NEED

The Central Artery/Tunnel (CA/T) Project is this country's most ambitious and technically challenging urban reconstruction project in history. The project is federally-funded by the Federal Highway Administration (FHWA) as well as state-sponsored through the Massachusetts Turnpike Authority (MTA). The joint venture of Bechtel/Parsons Brinckerhoff has been managing the design and construction of this mega-project since its inception in 1986. Construction is taking place around-the-clock in close proximity to thousands of residences and businesses, rebuilding the City of Boston from the ground down. Construction will take over 12 years to complete (expected in 2005), and the total project cost is expected to exceed $14 billion. Even though the project has understandably disrupted normal traffic flow and has been the target of people's frustrations, the project has also allowed for numerous advances in construction technologies. One of the many benefits that has resulted from this Aground breaking@ project involves the proven ability to anticipate community reaction to construction noise and the evolution of an environmentally-friendly Acan do@ mentality to proactively mitigate excessive noise.

As of the Summer of 2001, the project is 99% complete for design and about 70% complete with its construction. However, one more very large construction contract still needs to be prepared and put out for bid. This final remaining contract, known as C17A6, will be scoped to demolish and remove the existing elevated I-93 Artery, complete several underground tunnel sections, build ramp roofs over boatwall sections, rehabilitate the existing Dewey Square Tunnel, and restore all the surface streets throughout the project alignment. As shown in Figure 1, the C17A6 contract limits extend from Kneeland Street in the south, to the Charles River in the north, a distance of some 2 miles right through downtown Boston. While the winning bid and contractor have not yet been determined, internal estimates expect the C17A6 contract to cost about $440 million.

The project had a unique opportunity (and a mixed blessing) with the C17A6 contract. The high standards that the project has set over the past several years for managing construction noise has led to equally high public expectations that noise control will remain a top priority. In fact as far back as 1998 project engineers and community members started the process of minimizing and mitigating noise associated with anticipated C17A6 work activities. The resulting noise analyses, development and consideration of mitigation options, interactions with the affected public, and willingness on the project=s part to commit to proactive noise control measures make the C17A6 contract the most noise-scrutinized construction contract in United States history. The several years leading up to the release of the C17A6 contract for bid gave project engineers the opportunity to thoroughly evaluate any and all noise-related consequences and options, but it also gave the public an opportunity to press for even greater commitments than previous precedence had set. In the end, over $3 million-worth of noise control materials such as noise barriers and acoustical windows, and perhaps another half million dollars-worth of dedicated project personnel were committed to the public and incorporated into the C17A6 contract in order to mitigated anticipated noise.

C17A6 NOISE STUDY APPROACH

As a result of increasing public concerns regarding noise associated with the future C17A6 contract, two noise studies were performed during 1998 to 2001 (see Figures 2 and 3) in order to predict potential noise consequences and develop candidate noise mitigation measures. The two noise studies predicted noise associated with various construction equipment and phases of C17A6-related work operations during both daytime and nighttime periods. Potential adverse noise impacts were evaluated against criteria limits contained in the CA/T Project's Construction Noise Control Specification 721.560 [2] for more than 50 commercial and residential receptor locations. Where predicted noise levels exceeded allowable noise criteria limits, candidate noise mitigation measures were developed for consideration and adaptation. A large part of the noise mitigation process involved community input, and once finalized, the noise studies and the approved noise mitigation measures were incorporated into the C17A6 contract documents and committed to the public.

Construction Noise Criteria. Developed to be consistent with the intent of the City of Boston=s Noise Code [3], the CA/T Project adopted and refined the most comprehensive Construction Noise Control Specification 721.560 [2] of any public works project in the country. The specification contains both "relative" noise criteria limits at identified noise-sensitive receptor locations as shown in Figure 4, as well as "absolute" noise emission limits for any/all specific equipment used on site. The Noise Spec's lot-line criterion states that construction-induced L10 noise levels can not exceed baseline (pre-construction) L10 noise levels by more than 5 dBA at identified noise-sensitive receptor locations. L10 noise limits are intended to address, and have in practice been shown to correlate well with, more steady construction noise averaged over some time interval (20 minutes). Lmax noise limits also apply at the receptors= lot-lines and are intended to address loud impact-type noise events. The Noise Spec takes into account noise sensitivity during various time periods as well as for various receptor land-uses, as shown in Figure 4. To be allowed to work on a job site, each piece of construction equipment must comply with Equipment Noise Emissions Limits (Lmax, dBA, slow, at 50 ft) which are also contained in the Noise Spec for various generic types of construction equipment.

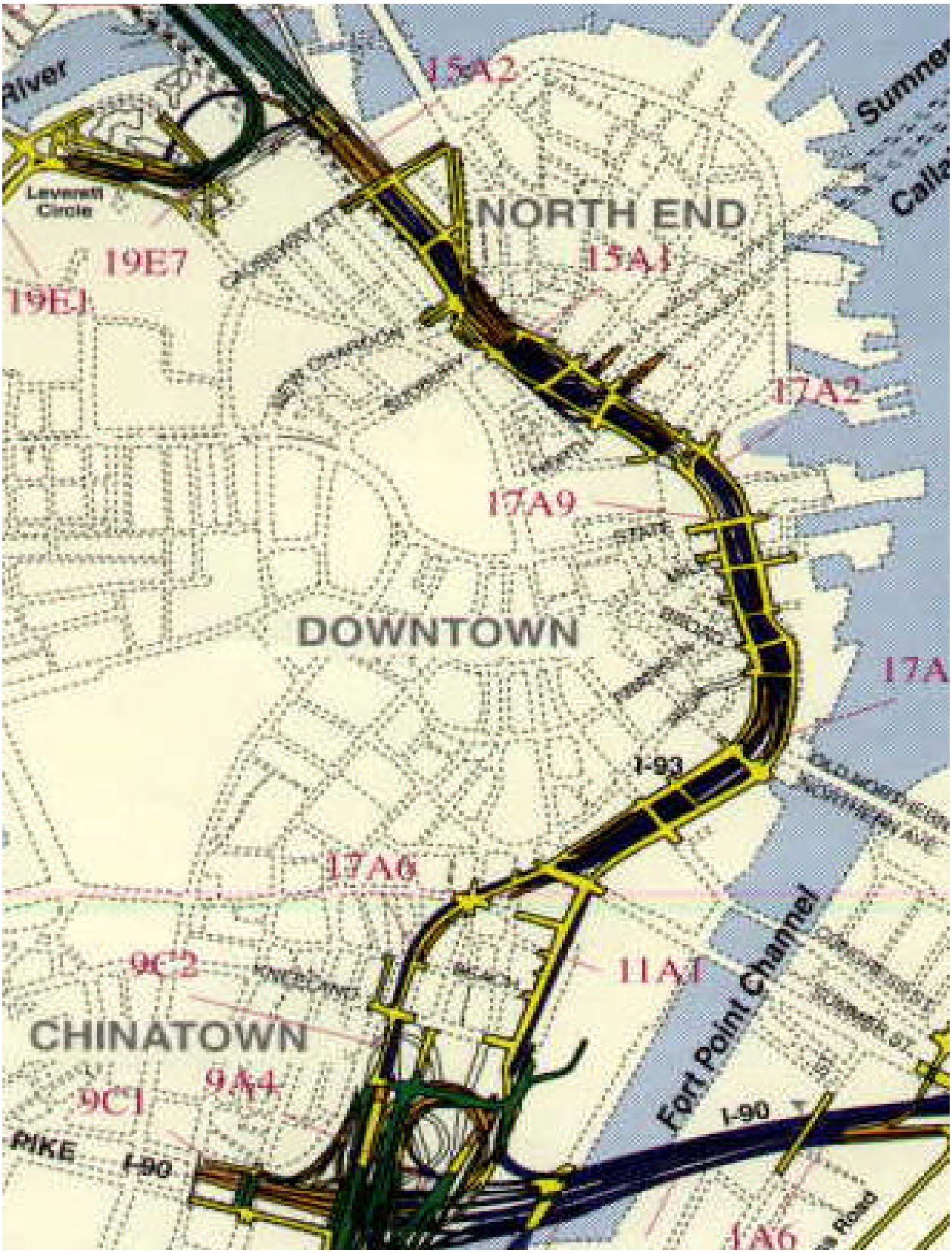

Figure 1. C17A6 Contract Project Limits

C17A6 Noise Study

Noise Analysis and Mitigation Options
Part 1: State Street to Charles River

Expressway Demolition
Ramp Roof Construction
Surface Street Restoration

Final Report
14 June 1999

Figure 2. (left)
C17A6 Noise Study Part 1
State Street to Charles River

C17A6 Noise Study

Noise Analysis and Mitigation Options
Part 2: Kneeland Street to North Street

Dewey Square Tunnel Rehabilitation
Elevated Expressway Demolition
I-93 Mainline Tunnel Construction
Surface Street Restoration

Final Report
30 March 2001

Figure 3. (right)
C17A6 Noise Study Part 2
Kneeland Street to North Street

Figure 4. CA/T Project Lot-Line Noise Criteria Limits

Noise Receptor Locations and Land-Uses	Lot-Line Construction Noise Criteria Limits in dB(A), 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 or Baseline+5 *(which ever is louder)*	85 90 (impact)	Baseline+5	85	Baseline+5 *(if Baseline < 70)* Baseline+3 *(if Baseline ≥ 70)*	80 80
Commercial Areas: (Businesses, Offices, Stores, etc.)	80 or Baseline+5	None	None	None	None	None
Industrial Areas: (Factories, Plants, etc.)	85 or Baseline+5	None	None	None	None	None

Noise Prediction Methodology. Noise predictions associated with planned demolition and construction operations in the C17A6 contract were performed in accordance with methods and algorithms contained in the CA/T Noise Spec 721.560. First, construction equipment groups were assumed for the various phases of C17A6-related work, which included (1) demolition and removal of the elevated I-93 Artery, (2) demolition and rehabilitation of the existing Dewey Square Tunnel, (3) completion of ramp roofs over boatwall sections, (4) completion of various mainline tunnel sections, and (5) restoration of all surface streets. Equipment assumed to work day and night included cranes, backhoes, loaders, dump trucks, concrete pumps, mixer trucks, delivery trucks, pneumatic tools, graders, pavers, compactors, and generators. Particularly loud equipment which was only assumed to operate during the day included pile drivers, jackhammers, how rams, and saws.

Noise emission source strength levels were taken from CA/T Noise Spec databases which provided equipment Lmax emission levels expressed in A-weighted decibels (dBA, slow) at a reference distance of 50 feet. Similarly, equipment acoustic usage factors, or the percent of time the equipment is assumed to operate at full power, were taken from CA/T databases. Then, the noise contribution from each piece of equipment was projected over the distance from the equipment to each respective receptor location. The primary equation used in predicting construction-induced L10 noise levels at receptor locations, when summed over all operating equipment, is as follows:

$$L10 \text{ in dBA} = Lmax@50ft - 20 \text{ LOG } (D/50) + 10 \text{ LOG } (U.F.\%/100) + 3 - ILbar$$

Where: *Lmax@50ft* is the emission limit for the equipment at 50 feet.
D is the distance, in feet, between the equipment and the receptor.
U.F.% is a time averaging equipment usage factor, in percent.
ILbar is the insertion loss of any intervening barriers, computed separately.
The +3 dB(A) adjustment factor was empirically determined by examining the average difference between Leq and L10 noise levels over many hours of construction noise measurements.

With the daytime and nighttime noise levels predicted at the various commercial and residential receptor locations, a comparison was performed to determine if predicted noise levels exceeded applicable Noise Spec limits (per Figure 4 above). The baseline noise levels and lot-line noise limits were taken from previous CA/T contracts in the same vicinity because they had proven over time to be fair and reasonable criteria that allowed contractors to progress their work while allowing the community to get the peace and quiet it required. Of the 50 residential and commercial receptors evaluated in the two C17A6 noise studies, predicted noise levels at 35 receptor locations (70 %) exceeded applicable Noise Spec limits, so candidate noise mitigation measures were warranted for development and consideration. The relative severity of noise exceedance conditions were subjectively described in the studies as follows:

"Minor" impact if the L10 noise level is predicted to exceed Noise Spec limits by *less than 5 dBA*.
"Moderate" impact if the L10 noise level is predicted to exceed Noise Spec limits by *5 to 10 dBA*.
"Substantial" impact if the L10 noise level is predicted to exceed Noise Spec limits by *10 to 15 dBA*.
"Major" impact if the L10 noise level is predicted to exceed Noise Spec limits by *more than 15 dBA*.

NOISE MITIGATION MEASURES

As a result of noise levels being predicted to exceed Noise Spec limits at so many receptor locations, candidate noise mitigation measures were developed and assessed for their reasonability and feasibility. In general, mitigation measures were developed to reduce noise at the source itself, along the pathway, or at receptor locations directly. The affected communities abutting the C17A6 contract were involved throughout the process to develop mutually acceptable noise mitigation measures. Ultimately, CA/T project officials decided to approve the following noise control measures, which were then subsequently incorporated into the C17A6 contract's Noise Spec section 721.560 before it went out for public bid in early April 2001.

Prohibition of particularly noisy equipment at night. Particularly noisy equipment and operations will be prohibited from use during nighttime hours (i.e. 10PM to 7AM) including such equipment as pile drivers, hoe rams, jackhammers, and concrete saws. In all cases regardless of time of day, equipment will have to meet its respective 50-ft noise emission limit in order to be allowed to work on site. These operational time constraints and equipment noise emission limitations were long-standing policies at the CA/T Project, so they represented no incremental cost to the C17A6 contract.

Noise barriers and curtain systems. Extensive use of portable noise barriers and noise curtain systems will be relied upon to reduce noise along the pathway between the noise producing equipment and the receptor locations. Per the Noise Spec, a barrier or curtain must achieve a Sound Transmission Class (STC) of 30 or greater in accordance with ASTM Test Method E90 [4] and be constructed from a material having a surface density or at least 2 lbs/sq.ft. to ensure adequate transmission loss characteristics. Noise barriers will be built as tall as practicable (about 14 ft tall) from "jersey" style concrete bases and plywood panels. Light-weight concrete block (4'x4'x10') or vertically planted I-beams with soldier pile lagging may also be used for more permanent noise barriers. Noise curtains made of thick (1/4 inch) vinyl with noise-absorptive quilt material will be draped down to enclose work zones under the elevated Artery. In addition, clear vinyl curtain strips will be draped over the Dewey Square Tunnel portals to contain noise within the tunnel yet allow construction vehicles to drive through the curtains. In total, some 132,000 sq.ft. of noise barriers, another 24,000 sq.ft. of noise curtains, and about 7,200 sq.ft. of clear curtain strips were approved. At an assumed unit cost of $20 to $25 per sq.ft. (installed) for new materials, the cost for all the noise barriers and curtains was estimated to be about $3.3 million. However, a more realistic cost estimate which assumed the barriers and curtains could be reused and relocated as needed reduced the cost estimate by about one third, or down to about $2.2 million.

Acoustical window treatments for eligible bedroom windows. Since 1997, the CA/T Project has had great success at reducing construction noise through the use of acoustical window treatments [5]. Eligibility criteria to determine which residences receive window treatments are contained in the project's Off-Site Noise Mitigation Policy [6] which takes into account such factors as measured or predicted noise levels, duration of the work, ability to reduce the noise by other methods, history of noise complaints, and cost. In most cases, the provision of an additional interior glass sash can provide an incremental improvement of 10 dBA noise reduction through a treated bedroom window. In the case of the C17A6 contract, noise prediction models indicated that even with the expected mitigation provided by the approved noise barriers and curtains, as many as 100 residences representing some 400 bedroom windows would still be eligible to receive acoustical window treatments at a cost estimate of about $260,000. Fortunately, many of the eligible residences already had their bedroom windows treated by the CA/T Project to mitigate noise from previous construction work, so the incremental cost for new C17A6-related window treatments was only about $100,000.

Prohibition of audible backup alarms from 11 PM to 6 AM. The use of audible backup alarms at night has been the greatest cause of noise complaints received by the project to date, and was understandably the community's greatest concern with C17A6 work expected to occur around-the-clock. Based largely on the success of pilot programs attempted in previous CA/T construction contracts, project officials decided to extend the prohibition of audible backup alarms from 11 PM to 6 AM throughout the entire C17A6 contract (except inside tunnels providing the backup alarms can not be heard above ground). The contractor will still be required to meet OSHA safety guidelines regarding safe vehicle rearward movements. The only alternative method acceptable to OSHA involves the use of observers to direct vehicles movements [7]. Cost estimates to provide dedicated observers ranged widely from $100,000 to $500,000 - but in practice it is believed that the contractor will simply use laborers already on site to direct vehicle movements so there will likely be no additional cost to implement this mitigation option in the C17A6 contract.

Maintaining the nighttime noise patrol and community liaison programs. The C17A6 contract will maintain the here-to-fore successful use of the nighttime noise patrol and community liaison programs. Many noise complaints can be proactively avoided, and better management and control of conditions in the field can be accomplished through the use of a dedicated noise technician to patrol the project at night. Should the project receive a noise complaint, the noise technician is able to immediately respond to the scene and investigate the circumstances that led to the complaint. The noise technician is empowered to intervene directly and shut down otherwise unmitigatably noisy operations that are exceeding Noise Spec limits and/or causing noise nuisances. Also, the project's community liaison program provides regular construction update meetings with the affected communities. Peoples tolerance to noise does increase when they are told what to expect and know that they can contact the project should they have any noise concerns. The cost to retain several staff as noise patrol and liaisons could amount to $1 million over the four years the C17A6 contract is expected to last. However, since other CA/T-related project work will be occurring concurrently with the C17A6 contract, the cost to extend both the noise patrol and liaison programs was considered incidental to the project's progress.

Shifting work to weekend days rather than week nights. Because of the operating limitations placed on the contractor due to high traffic volumes during the day, some work operations were necessarily scheduled for nighttime periods. At the community's urging, project schedulers evaluated the implications of performing some of this necessary work on weekend days rather than at night during the week. There is a cost premium for performing work on the weekends (e.g. double-time on Sundays) but some of the necessary night work could be accommodated during weekend days. Noise mitigation measures such as noise barriers will still be used during these weekend shifts, but full compliance with Noise Spec limits could not be guaranteed during these accelerated weekend day work shifts. The potential incremental labor cost to shift certain work tasks to weekend days was estimated to cost $1 million.

KEY LESSONS LEARNED

Given its size and scope, the Central Artery/Tunnel Project has been, and continues to be, the focus of intensive local, national, and international attention. The project has afforded the opportunity to elevate the state-of-the-art for all forms of construction-related techniques and mitigation strategies. The noise mitigation lessons learned through some 10 years of active construction served well towards preparing for the project's final large construction contract, C17A6. The project's noise mitigation program and policies have proven that construction noise can be successfully mitigated on a large-scale project in a balanced manner that allows abutting residences and businesses get the peace and quiet they require while allowing construction work to progress as well [1]. Some of the key lessons learned through the development of the C17A6 contract noise mitigation process are as follows:

- The affected communities must be actively involved in the development process of suitable noise mitigation measures and policies.
- A technical consultant working for, and selected by, the community serves well to assure the community that the project is being forthright and acting in good faith.
- Objective construction noise prediction studies can serve to guide project managers where and how to best spend noise mitigation funds in a technically- and cost-justifiable manner.
- A relative noise increase criteria, essentially limiting construction noise not to exceed baseline L10 levels by more than 5 dBA at receptor lot-line locations, has proven to be fair and manageable.
- A comprehensive Construction Noise Control Specification is essential for setting noise criteria and restrictions in an unambiguous manner and for avoiding costly noise-related claims from contractors.
- The cost of construction noise mitigation measures represent only a fraction of the overall cost to complete a large-scale construction project, yet the benefits of the noise mitigation measures and good graces they engender with the affected communities are essential for progressing project work.

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