# Arizona's Experience with a Construction Noise-Abatement Incentive

G. BRUCE KAY

Most of the efforts to reduce highway noise impacts have focused on protecting the public from present and future traffic noise. People have progressively become aware that highway construction operations can also generate a great deal of irritating noise, particularly if such operations occur during hours when people are more sensitive to noise. Most construction noise analyses justify the impacts as temporary inconveniences and try to establish limits on hours of operation. Such limits were not possible in the administration of pavement grinding contracts on an urban freeway in Phoenix. The reasons for the problems encountered in setting and enforcing noise-level limits for nighttime construction operations are discussed. A noise-abatement incentive was established to encourage potential bidders to silence noisy construction equipment, specifically the grinding machines. The formula used to establish monetary awards was developed with the intent of compensating the contractor for initial muffling efforts, and rewarding him for innovations to further reduce noise impacts. An account is given of the first contract that used the noise-abatement incentive, the resulting reductions in noise levels, and the reactions of the contractor and residents.

Most of the efforts to reduce highway noise impacts have focused on protecting the public from the effects of traffic noise. The temporary impacts of highway construction noise on the public, although potentially greater than traffic noise, have routinely been held subordinate to the long-term benefits of the final product. The public, however, is currently more vocal in objecting to invasions of privacy. Consequently, many projects are scheduled for times when conflicts are minimal or contain provisions for reducing the chances of environmental impact.

The Interstate system in Phoenix, as in most cities, is paved with portland cement concrete (PCC). This pavement is durable, rigid, and resistant to wear from high volumes of traffic. When it begins to show stress, some form of rehabilitation or reconstruction is necessary.

A technique for rehabilitation was developed, which evolved from grooving projects in the early 1960s, by which surface irregularities could be leveled out and the pavement grooved in one operation. The term grinding was adopted for the operation. Grinding is now considered to be an economic alternative to repaving or reconstruction, and it can extend the life of a roadway by 10 years or more.

Pavement grinding in Phoenix is subject to some unique restrictions. Contractors in the Southwest prefer to grind in the winter and at night to reduce the effects of heat on the equipment. Project managers share that opinion because of the reduced nighttime traffic involved. Contractors thus have greater flexibility and better quality control for grinding and related work.

Conversely, residents adjacent to the freeway are generally more sensitive to occurrences at night. They are exposed to the combination of freeway traffic changes and the grinding operation from 10:00 p.m. to 6:00 a.m. for periods of 2 days to 2 weeks. The new noises are much harder to get used to than customary freeway traffic. Nevertheless, complaints are uncommon, primarily because most people still have a tolerant attitude. When one individual complains, a reasonable explanation usually alleviates his concern. If a group of concerned or affected residents complain, the agency may have to make an effort to reduce the noise impacts and still maintain the unusual construction schedule. Above all, complaints have to be responded to in a positive manner.

## HISTORY OF GRINDING IN PHOENIX

In the winter of 1974-1975, the Environmental Planning Services of the Arizona Department of Transportation (ADOT) was requested to study the noise levels emitted by equipment used in the state's first grinding project on I-17, Phoenix's Black Canyon Freeway south of Thomas Road (Figure 1). Monitoring of noise levels indicated that an upper noise-level limit could be specified in future contracts. It was believed that potentially sensitive areas should not be exposed to unreasonably high noise levels. Consequently, an upper limit of 86 dB(A) $L_{max}$ at a distance of 50 ft was set for all grinding activity before 11:00 p.m., and 82 dB(A) $L_{max}$ between 11:00 p.m. and 6:00 a.m. The equipment, when properly serviced, was capable of maintaining these levels. Examination of the specifications in other states verified that 86 dB(A) or less generated few complaints. It was not recognized at the time that there were as many designs of grinding and grooving operations and equipment as there were contractors (Figures 2 and 3). A few companies designed cutting heads and blades, but generally the equipment was built and maintained by the contracting companies. The noise emissions of machines could differ by several decibels.

A project covering the northbound lanes of I-17 was initiated some years later. The same contractor, with essentially the same set of grinders in a deteriorated condition, stated that any additional shielding of the engines to bring the levels within specifications would contribute to further deterioration. Consequently, the limit was relaxed to 86 dB(A) $L_{max}$ for each piece of equipment for the entire nighttime operation. Project managers believed that noise complaints could be handled with little difficulty. It was believed that by the time complaints were fielded, the equipment would have left a specific area.

The project proceeded smoothly during the first 8 months, with a few complaints from residents. But during the next month residents west of one 0.25-mile segment were not satisfied with the usual response and complained to ADOT management, the state Department of Health Services, and ultimately to the Governor's office. Subsequently, ADOT was asked to reduce the potential noise impacts of future projects.

The noise complaint would not have become a problem if the breakdowns and delays associated with several unexpected factors had not occurred. The equipment was in need of repair and modification. The concrete on the Black Canyon Freeway was composed of extremely hard aggregate, and the design of the diamond blades was not adequate for this project. The rate of grinding was much slower than the normal 10 to 15 ft per minute. Furthermore, the pavement deflections were so great in this section that repeated passes over large areas were required.

ADOT continued to receive inquires from the complainants after project completion, and in response more stringent noise-level limits were developed.

Figure 1. Vicinity map.

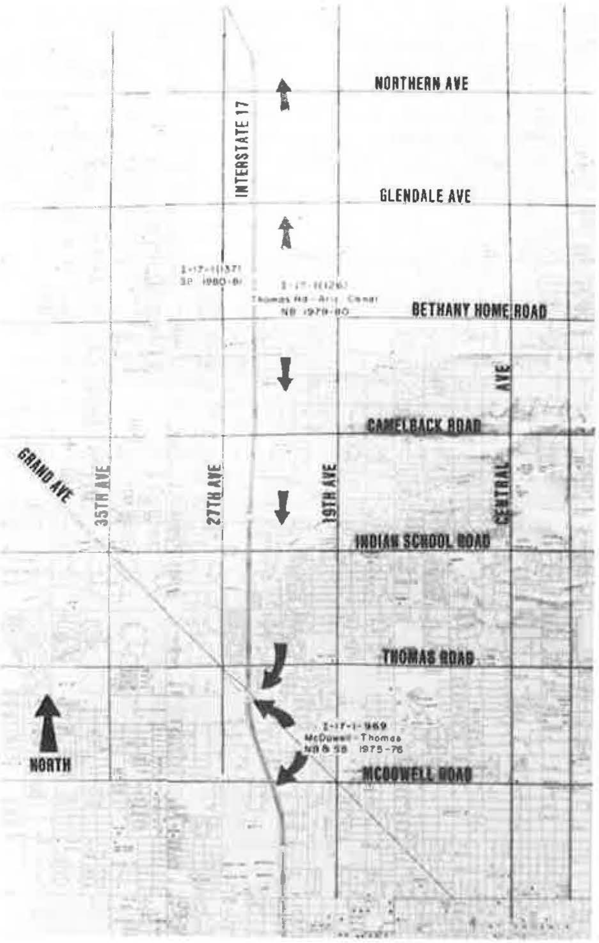



Figure 2. One manufacturer's model of a pavement grinder.

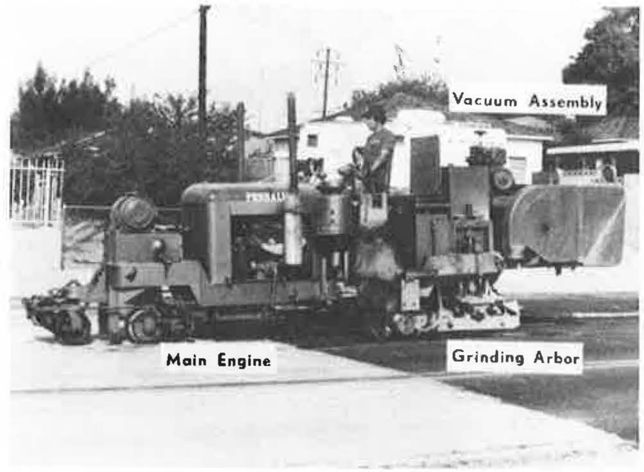
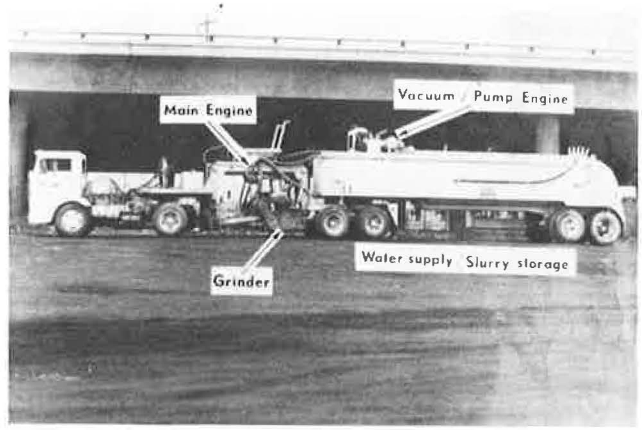



Figure 3. Model of grooving equipment.




In a prebid conference for the following project on the southbound lanes, several contractors threatened not to bid if the specifications on noise levels were maintained or tightened. ADOT management suggested that a provision for monetary incentives for noise abatement be studied. Following FHWA concurrence, manufacturers and contractors were contacted to try to understand their positions and to inform them of the proposed efforts. Their input was mixed, obviously, but overall there was approval of the incentive concept. Their technical comments were considered in the development of the incentive.

EVALUATION OF MITIGATION MEASURES

The main concern at ADOT was to significantly reduce the noise impacts at residential properties, or at least to be able to inform residents that measures were taken to reduce noise impacts. Also, ADOT wanted to offer a monetary value that was an incentive for the potential contractors to experiment with noise-reduction techniques. The Department started with a baseline $L_{max}$ of 86 dB(A) at 50 ft, and considered graduating payments for each decibel reduction from that level.

The first step was to identify the primary noise sources and the potential for retrofitting silencers. These sources consist of (a) the 250- to 400-hp air- or water-cooled diesel engines used to power the drive train and the arbors (cutting heads), (b) the generally smaller air-cooled diesel engine used to operate the slurry vacuum and blower system, (c) the vacuum and blower system, and (d) the arbors (grinding heads) in contact with the pavement. The typical locations of these components are shown in Figures 2 and 3.

In the case of the engines, premanufactured mufflers for engine exhausts were found to be readily available. In addition, modification of the fans and shrouding of the engines (Figure 4) could provide additional reduction if needed.

The vacuum and blower noise levels were also reducible with the addition of mufflers (Figure 5). Manufacturers claimed significant insertion losses ranging up to 30 dB for the middle frequencies. The primary noise stems from the intake and the discharge of high volumes of air to the atmosphere.

The noise levels generated from the actual grinding, done with an arbor (Figure 6), cannot be distinguished from the other sources. Furthermore, many machines are equipped with shrouds of heavy fabric to retain the water and slurry within the limits of the vacuum inlets. These shrouds are effective shields.

It was estimated that noise levels could be reduced to 80 or 81 dB with the full complement of silencers. This value was not calculated; it was measured by one equipment manufacturer at its plant.

With silencing of the sources, further reduction

Figure 4. Front and rear views of a typical noise-insulated diesel engine.

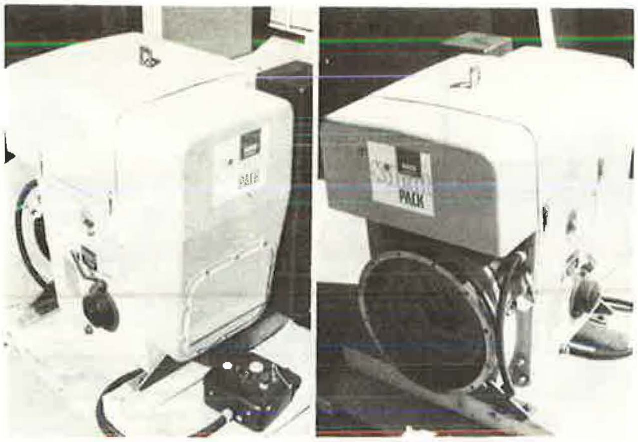


Figure 5. Typical silencer installed on rotary positive blowers or vacuums.

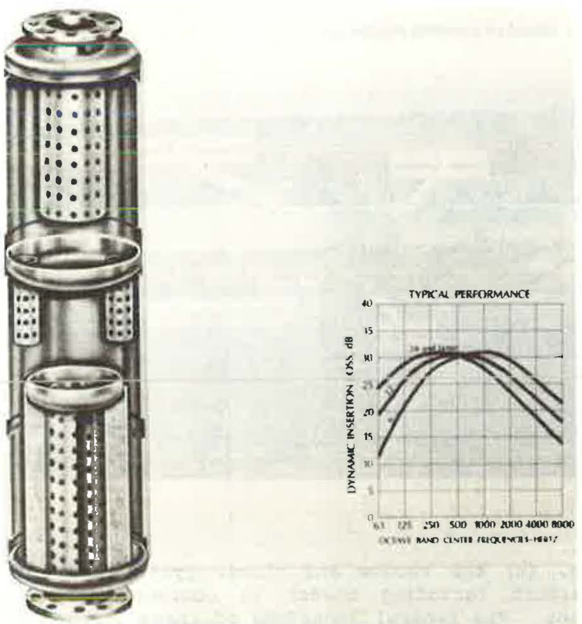
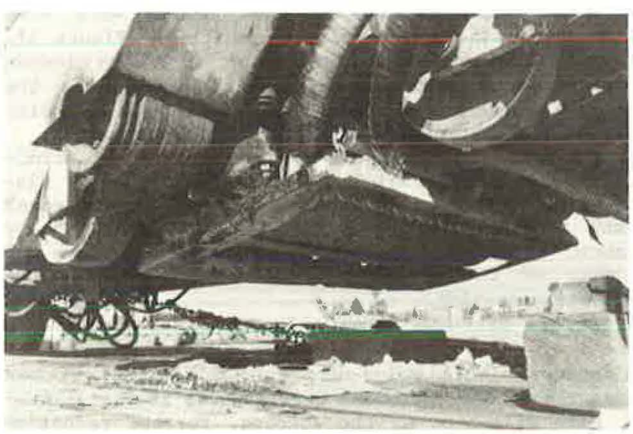



Figure 6. Grinding arbor—a cutting wheel composed of diamond chips embedded in steel disks.



was considered possible by inserting a portable barrier of some type between the source and any sensitive receivers. The manufacture of such a barrier was believed to be possible by using a 20- to 30-ft-long metal frame fitted with lead-loaded vinyl curtains suspended from a height of 10 ft or more. An efficient barrier would provide a 10- to 13-dB insertion loss. However, because of end effects, it was predicted that a resultant reduction of 6 to 7 dB would occur at the ends of the barriers (Figure 7).

THE FORMULA AND ITS APPLICATION

A monetary incentive formula was derived to provide about-even compensation for the cost of engine muffling and modifications and larger payments for efforts to further reduce noise levels at the source or in the transmission path. The formula was designed to be applied for the duration of the project, with payments calculated monthly, taking into account the number of grinders used and the incremental percentage of work completed. If equipment deterioration resulted in higher noise levels, this procedure would lower the monthly payment. If the 86-dB(A) limit was exceeded, the violating equipment would be shut down until repaired or modified.

The formula used on the project is as follows:

$$G = HC/D \tag{1}$$

where

$H = F(86 - A)^{1.5}/10^{1.5}$,
A = average decibel reading for all grinders used for 60 percent or more of the current month,
C = square yards of completed ground PCC pavement per month,
D = total square yards of PCC pavement in bidding schedule,
F = total maximum incentive part in bidding schedule (see Table 1),
G = total payment for each month,
G (TOT) = sum of all G's, and
H = noise-abatement incentive payment (see Table 1).

The values of payments for noise levels sustained over a project are given in Table 1. The exponent applied was derived empirically, with the assumption that an average of three machines would be used on a project. The exponent gave H values, or payments, that should compensate for the costs of retrofitting noise sources and would provide greater payments for further reductions.

The data in Table 2 give an example, not related to the project, of how the formula is used. Payments are made monthly and are based on the measured area of pavement grinding completed for that period, its relative ratio to the total area in the contract, and the arithmetic average of the noise levels of all grinders used during that period. The product of H--the payment amount for the average level and the fraction of work completed--is the monthly payment.

MEASUREMENT AND MONITORING OF EQUIPMENT

To control the application of the incentive formula, measurement and monitoring procedures had to be specified. The major features of the specification included the following:

1. Definition of the grinder to include all related equipment, including water trucks;

Figure 7. Plan view of Black Canyon Freeway showing the relative position of the points of maximum exposure to the noise levels with and without a portable barrier.

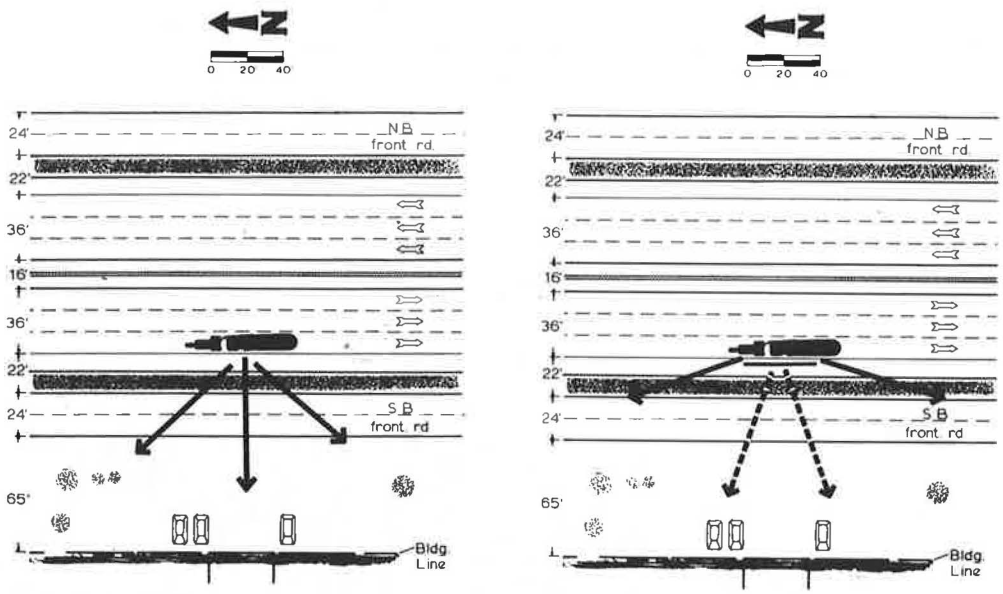



Table 1. Noise-abatement incentive payment levels.

| A [dB(A)] | $H^a$($) | A [dB(A)] | $H^a$($) |
|---|---|---|---|
| 86 −½ | 0 | 80 ±½ | 23,238 |
| 85 ±½ | 1,582 | 79 ±½ | 29,283 |
| 84 ±½ | 4,472 | 78 ±½ | 35,777 |
| 83 ±½ | 8,217 | 77 ±½ | 42,690 |
| 82 ±½ | 12,684 | ≤76 ±½ | 50,000 |
| 81 ±½ | 17,678 | | |

[a] F = $50,000.

Table 2. Example of how noise-abatement incentive payments would be made.

| Month | C ($yd^2$) | C/D | A | H($) | G($) |
|---|---|---|---|---|---|
| 1 | 16,625 | 0.125 | 84.8 | 1,582 | 198 |
| 2 | 13,300 | 0.100 | 76 | 50,000 | 5,000 |
| 3 | 19,950 | 0.15 | 78 | 35,777 | 5,367 |
| 4 | 26,600 | 0.20 | 79.7 | 23,238 | 4,648 |
| 5 | 16,625 | 0.125 | 80 | 23,238 | 2,905 |
| 6 | 16,625 | 0.125 | 77.1 | 42,690 | 5,336 |
| 7 | 11,970 | 0.09 | 76.4 | 50.000 | 4,500 |
| 8 | 11,305 | 0.085 | 75 | 50,000 | 4,250 |
| Total | 133,000 | 1.0 | | | 32,204[a] |

Notes: For definition of column headings, see Equations 1 and 2.
D = 133,000 $yd^2$, and F = $50,000.
[a] $32,204 = G(TOT).

2. Position of the measurement point at 50 ft from the path of the grinding equipment (this distance satisfied the goal of monitoring the hard sites over most of the project);
3. Recording of the maximum level and location of equipment relative to the microphone position, with the requirement that the equipment be in the production mode;
4. Provision for the engineer to monitor noise levels at any time in the project;
5. Provision for retesting any grinder if monitoring indicated that a change in levels had occurred;
6. Physical conditions of the measurement and monitoring area, i.e., flat terrain with no obstruction or reflective surfaces not related to the project; and
7. Specifications for the sound-level measuring equipment; i.e., the reference to American National Standards Institute (ANSI) standards for type 1 or type 2 meters.

IMPLEMENTATION OF THE INCENTIVE

The initial use of the incentive came in October 1980. The advertising phase did not elicit prebid responses to the specification for noise-level limits or to the incentive amount, which was set at a maximum of $50,000. ADOT was restricted from using the specifications to suggest abatement measures, primarily because of concerns for liability if they were unsuccessful.

The national exposure that the previous contract received prompted one equipment manufacturer to conduct research into the design of the diamond cutting blades for the highly resistant aggregates used in Phoenix's local concrete. They went to the expense of having slabs of local concrete shipped to their plant for extensive testing. In addition, the grinding subcontractor, whose equipment was manufactured by the same company, shipped three grinders to the plant to have them retrofitted with silencing devices. By project start-up, two machines were in production, and initial measurements were conducted.

The objective of the ADOT research was to record the maximum noise level of each grinder as it passed by 50 ft from the primary microphone. This maximum level occurred when the noisiest components were directly in front of the microphone. In the operating mode the average speed of the equipment was 7 to 10 ft per minute, which allowed time for recording. Freeway traffic was detoured onto a parallel street 0.5 mile from the facility for a 1-hr period.

The equipment used for measurement included a B&K type 2218 precision integrating sound level meter with an accessory dc strip-chart recorder, and a BBN model 640 programmable noise analyzer with digital printout of the statistical distribution of noise levels, programmed to update data every minute. One microphone was mounted 50 ft from the near edge of the equipment, and another was placed on a tripod in the frontage road about 75 ft from the equipment. A third meter, a Pulsar model 40, was supplied to the project engineer for use in monitoring noise levels during the project. Its accuracy was verified concurrently with the initial measurements.

Five months later ADOT was asked to measure noise levels of a third grinder that had been shipped to the project. This was accomplished with a 10-min shutdown of frontage road traffic. On the same night, measurements of the other grinders were conducted by using the B&K meter and strip-chart recorder under frontage road traffic. The test revealed that a minimum level could be attributed to the grinder; the frontage road traffic, 20 ft west of the microphone position, raised the level 6 to 10 dB. Traffic flow was intermittent because of signalization at a nearby interchange, and the quiet gaps were long enough to identify grinder noise levels. This finding was significant because it could reduce the time and personnel needed for the precision measurements. The specification requiring measurement at 50 ft restricted the measurement of noise levels when the equipment was in the inside lane, where the 50-ft position was on or inside the right-of-way fence, as shown in Figure 7. Obviously, if the same distance was maintained for the other lanes, the conflicts with traffic would become greater. The only alternative was to record levels from positions in the neighborhood area and adjust back to 50 ft with a point-source factor, i.e., 6 dB per double distance.

This alternative was confirmed with a third measurement. A microphone was located adjacent to the frontage road at 90 and 99 ft from each of two grinders that were operating in different lanes. When an adjustment was applied to 50 ft, the readings were consistent with previous measurements.

A fourth measurement was done in late May when the contractor was using only one machine. The contractor was finishing the last mile of the project. An increase in noise level had been reported by the project supervisor.

## RESULTS AND CONCLUSIONS

The initial measurements described in the preceding section were applied to the incentive formula. The original two grinders each had an $L_{max}$ of 82 dB(A) at 50 ft. The incentive would provide a total payment of $12,684 if the average was maintained throughout the project. The third grinder also had an $L_{max}$ of 82 dB(A) when it was first brought onto the project. Late in the project the contractor reduced his force to one grinder used on the last mile. Its noise level deteriorated to 84 dB(A).

The contractor finished the grinding phase on time, and no penalties were applied to the incentive award. Total payment for noise abatement was approximately $11,500. The contractor reported that the cost to retrofit the three grinders was $11,700. However, at least some measures used were required to meet the 86 dB(A) specification. The original equipment, when used in a project in Georgia, was measured at 95 dB(A) and greater. The net reduction, with retrofitting, was 13 dB or more.

The reduction measures were reportedly simple to install and easily changed if necessary. The exhaust system was modified, and mufflers were installed on both engines (Figure 8). The large diesel engine was fitted with insulated cowling (see Figure 9). The cooling fan was modified by revising rotation direction and changing its speed. Silencers were installed on the vacuum and blower assembly (Figure 10), and small shields were installed on the equipment near the smaller engine.

The deterioration in noise level noted late in the project was because of a reduction in efficiency of the vacuum system. A few leaks developed in the separator (shown in Figure 10), and the speed of the small diesel had to be raised to compensate for the loss of pressure. This deterioration began in the

**Figure 8. Main engine with modified exhaust mufflers.**

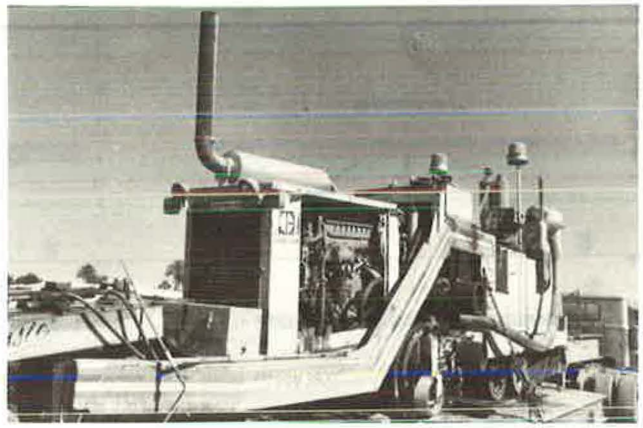


**Figure 9. Insulated panel for main engine, lined with 1-in.-thick foam rubber.**

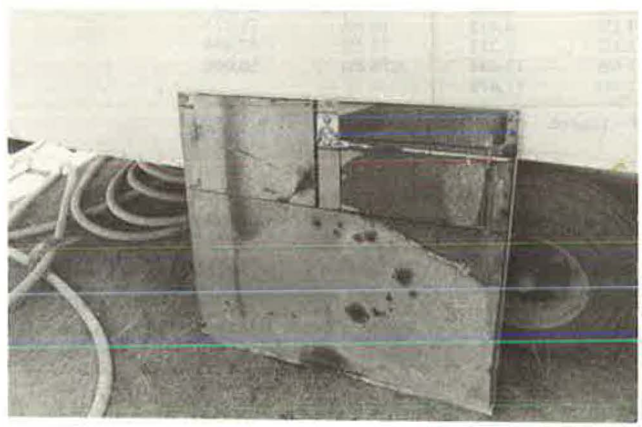


**Figure 10. Vacuum and pumping system with exhaust silencers on right rear; separator is on left rear.**

last 2 weeks, and its effect on residents was minimal.

Complaints were minimal throughout the 8 months of the project. The affected residents discussed earlier did not have time to complain. The grinding phase sped through their 0.25-mile segment in three nights. Other complaints received by project personnel concerned noise from other equipment used in peripheral phases of the project, i.e., power concrete saws used to clean joints and jackhammers used in patching damaged slabs. Their noise levels were less than those of the grinders.

It was believed that the lack of complaints was due in part to a significant reduction in noise levels of more irritating frequencies, even though the capability of verifying this information with instrumentation did not exist. The accessory equipment (jackhammers) had a noise impact because of their inherently higher frequencies. Furthermore, the diesel engines used on the previous contract emitted a pronounced whine, whereas the later engines and exhaust systems did not. Apparently the dampening effects of the retrofitting were significant.

The effects of the devices on overall performance of the equipment were negligible. The contractor was 5 weeks behind schedule when the first mile was completed, and delays were attributed to complications not related to the retrofitted equipment. Adjustments were made to the grinding process, design of blades, and a few other mechanical deficiencies. The project was finished on schedule. Naturally, the speed of production was a benefit to the residents.

The primary goals of reducing the inherent noise levels and reducing complaints were achieved. ADOT hopes to continue offering the same noise-abatement incentive on future sensitive projects, assuming the monetary award can be maintained at an attractive value.

Several factors that cannot be controlled may affect this decision. Larger-scale projects may require larger fleets of equipment. Overall noise levels may be more difficult to maintain at limits less than 86 dB(A). Retrofitting major components may be more expensive, and incentive payments may not be attractive enough. Larger fleets also mean more noise sources to monitor.

When compared with earth-moving equipment, the grinders are actually quite small. Most are designed to process a path width of 3 ft. However, some manufacturers are now testing machines with two arbors designed to grind 6 ft or more in one pass. The power supplies are much larger than those used in Arizona. Thus the potential for more intrusive noise is higher. Problems in attracting this more productive equipment may be encountered because of noise-level restrictions.

Obviously, future use of the incentive will have to be dealt with on a project-by-project basis. Sensitive areas will require protection, whereas other areas may not require any limits on noise levels. However, Arizona intends to protect people from excessive construction noise and will encourage innovations in noise reduction. In the near future ADOT hopes to set the primary noise-level specification to a more restrictive limit than 86 dB(A).

The need for more data on activities of other contractors is evident. The ability to sample more equipment is limited by the type of equipment that enters the state. ADOT needs input from other agencies that are collecting construction noise data of any kind. Considering the future of new highway construction versus rehabilitation and maintenance in sensitive urban areas, the need for noise abatement on construction projects may become much more important.

ACKNOWLEDGMENT

The preparation of this paper would not have been possible without the technical expertise of Larry Yeager and the assistance of Jack Siegfried, Romulo Robeniol, and the staff of Environmental Planning Services of ADOT. Furthermore, the noise-abatement incentive and subsequent study were made possible by the financial assistance of FHWA. Appreciation is expressed to FHWA division engineers who provided a constructive review of the paper.

*Notice: Opinions expressed herein are those of the author and do not reflect Arizona Department of Transportation policy.*

# Procedure to Evaluate Transit Noise Abatement and Cost-Effectiveness: The PEACE Program System

WILLIAM R. McSHANE, JOSE M. ULERIO, AND SIMON SLUTSKY

**The procedure to evaluate transit noise abatement and cost-effectiveness (PEACE) program system was developed as a tool that rail transit operators and others could use to evaluate the noise performance of their system and to explore the cost and effectiveness of candidate noise-treatment plans. The system uses three input data bases: (a) system description, (b) noise profile, and (c) treatments and costs. It is designed so that the latest state of the art in noise descriptions and in treatment technology can be incorporated, and that future developments can be added. It is also designed for use on large properties. The PEACE system is implemented as a set of three computer programs: a preprocessor, a main program, and a postprocessor or report generator. The system can be used to evaluate proposed treatment sets, to investigate the potential of hypothetical treatments or of new car designs, and to check a number of what-if questions. The development work was done with close interaction with a major rail transit property (New York City Transit Authority), which plans to use the PEACE system in its work.**

The procedure to evaluate transit noise abatement and cost-effectiveness (PEACE) was developed under contract to the U.S. Department of Transportation (DOT) to allow rail transit operators and other interested parties to

1. Systematically determine and review the noise levels on the system;
2. Systematically catalog the abatement measures