investigation. The selection of instrumentation requirements obviously depends on both the required complexity of the monitoring program and available funding. As part of the research program described in this paper, separate report volumes have been, or will be, prepared concerning procedural guidelines for water-quality impact assessment and detailed monitoring guides for conduct of field programs. These manuals are designed to serve the needs of highway department personnel by providing simple and straightforward procedures in design, planning, conduct, and evaluation of proposed sampling programs and water-quality investigations.

ACKNOWLEDGMENT

The research efforts described in this paper are being, or were, performed under the sponsorship of the Federal Highway Administration, U.S. Department of Transportation.

REFERENCES

1. D.M. Grant. Open Channel Flow Measurement Handbook. Instrument Specialties Co., Lincoln, NE, 1979.
2. Stevens Water Resources Data Book. Leupold and Stevens, Inc., Beaverton, OR, 1975.
3. C.E. Zobell. Apparatus for Collecting Water Samples from Different Depths for Bacteriological Analysis. Journal of Marine Research, Vol. 4, No. 173, 1941.
4. National Handbook of Recommended Methods for Water Data Acquisition: Chapter 3--Sediment. Office of Water Data Acquisition, U.S. Geological Survey, Reston, VA, 1978.
5. C.H. Mortimer. Chemical Exchanges Between Sediments and Water in the Great Lakes: Speculations on Probable Regulatory Mechanisms. Limnology and Oceanography, Vol. 16, No. 387, March 1971.
6. A.M. Lucas and N.A. Thomas. Sediment Oxygen Demand in Lake Erie's Central Basin 1970. Proc., 14th Conference on Great Lakes Research, Univ. of Toronto, Toronto, Ontario, April 1971.
7. M.K. Gupta and others. Sources and Migration of Highway Runoff Pollutants: Monitoring Plan (Phase II Study). FHWA, Revised Plan, Dec. 1978.

Publication of this paper sponsored by Committee on Instrumentation Principles and Applications.

Are Earth Berms Acoustically Better Than Thin-Wall Barriers?

J. J. HAJEK

The two most common highway noise barrier structures are earth berms and thin-walls. Yet the relative acoustical performance of these barriers is not well understood. Previous analytic, scale-model, and full-scale studies, comparing the acoustical effectiveness of thin-walls with that of berms and wedges, are reviewed. Additional data obtained by full-scale measurements, and in particular by a 1:16 scale-model study, are presented. The source-barrier-receiver geometry and model materials used were selected to simulate typical highway situations. Preliminary results indicate that, contrary to a recommendation in the Federal Highway Administration Highway Traffic Noise Prediction Model, thin-wall barriers and earth berms of the same height are about equally effective in reducing noise. In addition, the acoustical effectiveness of combining a wall with an earth berm was found to be quite similar to that of using thin-wall barriers alone. The practice of erecting relatively low walls on top of earth berms was found to be acoustically sound.

Reflective thin-walls, earth berms, and combinations of the two, are the most common highway noise barriers. Their relative nonacoustical aspects, such as cost, maintenance, right-of-way requirements, and aesthetics, are well understood (1), but their relative acoustical performance is not so clear. Whereas some highway noise prediction methods assume that they perform equally (2,3), the widely used Federal Highway Administration (FHWA) Highway Traffic Noise Prediction Model (4) asserts that earth berms provide 3 dB(A) higher insertion loss than do thin-walls of the same height. This difference in acoustical performance has been attributed to absorption or edge effects.

The higher insertion loss assumed for earth berms could lead to an important consequence: If the shape of the earth berms (presumably the cause of the increase in the insertion loss) is changed by erecting a thin-wall on its top, the 3-dB(A) benefit provided by the berm top may be lost. Figures 1 and 2 show two wall-berm combinations. Such combinations are quite common in many states. Relatively low walls have been added to improve performance in comparison with earth berms alone. But do they?

This concern is illustrated in Figure 3, which is based on our results from scale-model testing. Details of the scale-model testing, such as instrumentation, methodology, and additional results, are discussed later in this paper. For now, Figure 3 is intended only to illustrate the effect of mounting a thin-wall atop a barrier with an absorptive top.

According to Figure 3, mounting a thin-wall atop a highly absorptive barrier can actually reduce insertion loss. Only after the thin-wall is raised to the height of 1.2 m is the reduction in the insertion loss--caused by violating the absorptive cylindrical shape--recovered by the increase in barrier height. The question arises, Can the same phenomenon occur if a thin-wall barrier is erected atop an earth berm?

This question has become acute in Ontario since a proposal was made to build a thin-wall, approximately 2 m in height, atop an existing 3-m-high earth berm. The berm is already providing some insertion loss [about 6 dB(A)], so the rate of increase in the insertion loss with additional barrier height would be about 1.5 dB(A)/m. However, the desired 3-dB(A) increase in the insertion loss expected from adding

Figure 4. Source-barrier-receiver geometry: grass-covered ground shown by hatched area and hard ground by heavy line.

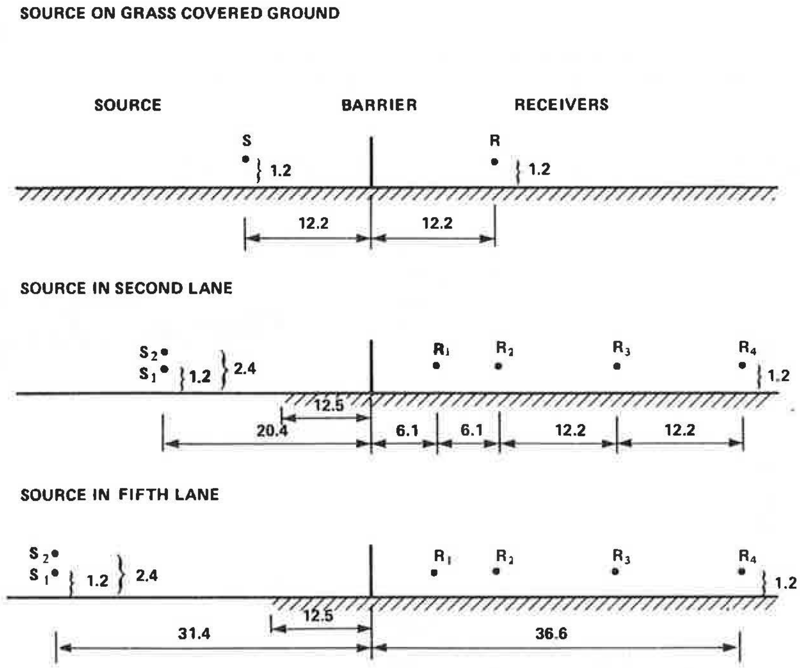


Table 2. Barrier shapes evaluated.

Barrier Height (m)	Type
3	Conventional barrier with vertical, reflective-surfaced walls 0.16 m thick
	Earth berm (rounded)
	Earth berm with distinct edges on top
4.9	Conventional barrier with vertical, reflective-surfaced walls 0.16 m thick
	Earth berm (rounded)
0.3-1.8	Conventional barrier atop 3-m-high earth berm
	Conventional barrier atop 3-m-high berm with sound-absorptive top

Barrier Height of 4.9 m

The acoustical performance of three different 4.9-m-high barriers--namely, a conventional thin-wall barrier, an earth berm, and a wall-berm combination--is compared in Figure 5. The source is in the fifth lane, 2.4 m aboveground, as detailed in Figure 4.

The insertion loss (i.e., the difference in sound level between the situations with and without the barrier, with no change in ground cover and source-receiver geometry) obtained for the three barrier shapes was quite similar; the lowest overall insertion loss was measured for the earth berm. The lower insertion loss provided by the earth berm in comparison with that of the thin-wall of equal height has been reported earlier (6) (Table 1) and can be tentatively attributed to two factors:

1. Sound waves diffracted into the shadow zone can also reach a receiver by reflection from the ground (29). In the case of earth berms, diffracted waves may also be reflected from the slope of the berm in the shadow zone.
2. Tilting the slope of a wedge while keeping its top at the same position alters its insertion loss because the position of the image source, with respect to the slope, shifts. As the wedge is spread out more (i.e., as the angle of tilt increases), the position of the image source shifts toward the base of the wedge and thus sound levels in the shadow zone increase. This is shown schematically in Figure 6.

The negative effect of these two factors on insertion loss is mitigated by the sound-absorptive properties of the berm surfaces and by the scattering and absorption losses taking place along the berm top.

No systematic difference between the conventional thin-wall barrier and the wall-berm combination was observed.

Barrier Height of 3 m

Insertion losses measured for 3-m-high barriers--a conventional barrier, an earth berm, and an earth berm with an "artificially" high sound-absorptive top--are shown in Figures 7 and 8. The two berms were identical except for a urethane foam used on the top of the absorptive berm. As mentioned before, the earth berm was completely covered with a special fiberboard material to simulate grass cover.

The berm with the sound-absorptive top was a somewhat "artificial" structure because the sound-absorptive property of the top (which had a noise reduction coefficient of 0.75) would be difficult to duplicate in the field. This structure was evaluated mainly to test whether and how the performance of a berm can be improved by using an absorptive material on its top.

The results in Figures 7 and 8 are based on the source height modeled 1.2 and 2.4 m aboveground, respectively. Both figures show that the 3-m-high conventional thin-wall barrier again slightly outperforms its earth berm counterpart. The replacement of the grass-covered top by the more absorptive top improved the berm performance by about 2 dB(A) for the source-barrier-receiver geometries used. This suggests that the absorptive material on the barrier top may be a more important influence of diffraction than the barrier shape.

Wall-Berm Combination

The effect of mounting a thin-wall conventional barrier atop an earth berm is shown in Figure 9. The height of the conventional barrier ranged from 0.3 to 1.8 m; the source-barrier-receiver geometry used is shown schematically in Figure 9 and is detailed in Figure 4.

Figure 5. Comparison of different 4.9-m-high barriers with source in fifth lane 2.4 m above ground.

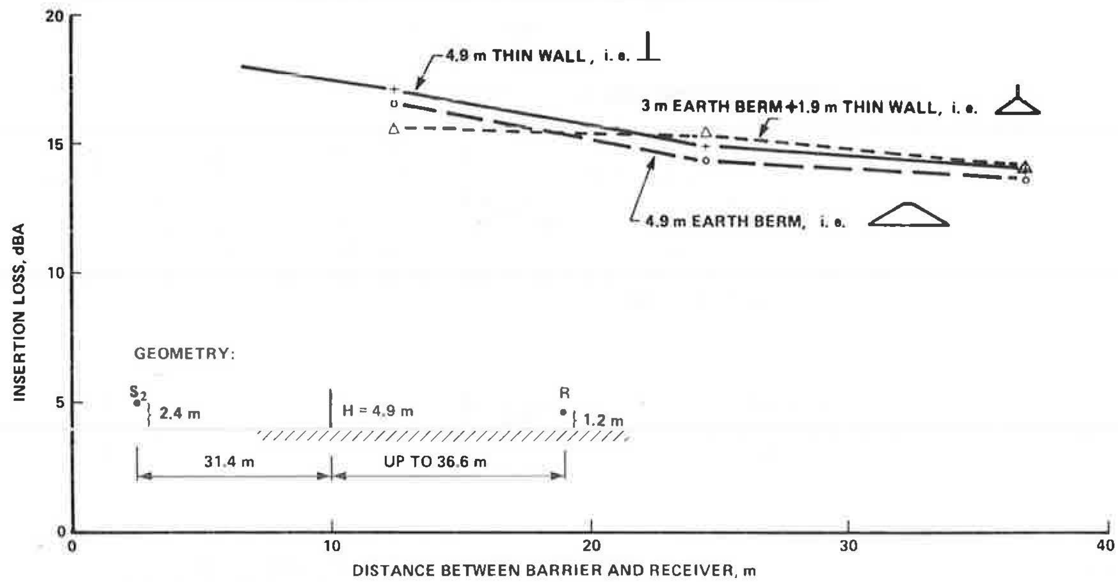


Figure 6. Effect of tilting the slope of a wedge: (left) small angle of tilt and (right) large angle of tilt.

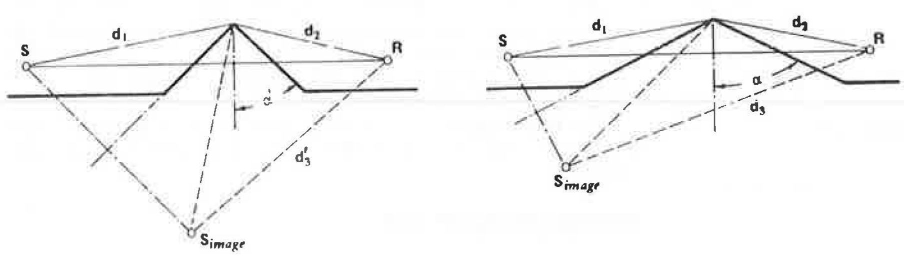


Figure 7. Comparison of different 3-m-high barriers with source in second lane 1.2 m above ground.

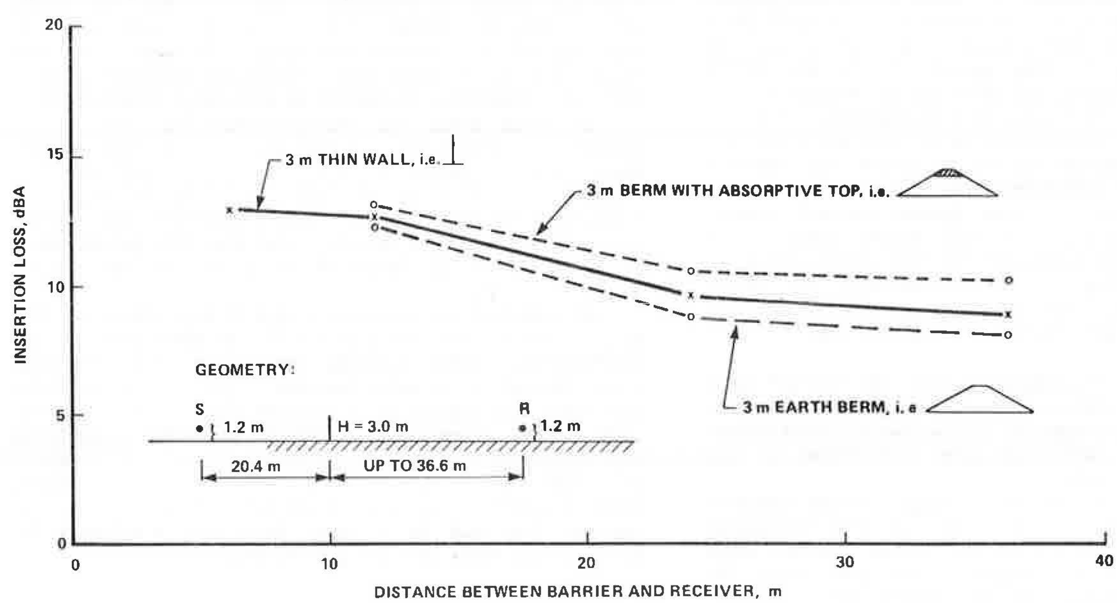


Figure 8. Comparison of different 3-m-high barriers with source in second lane 2.4 m above ground.

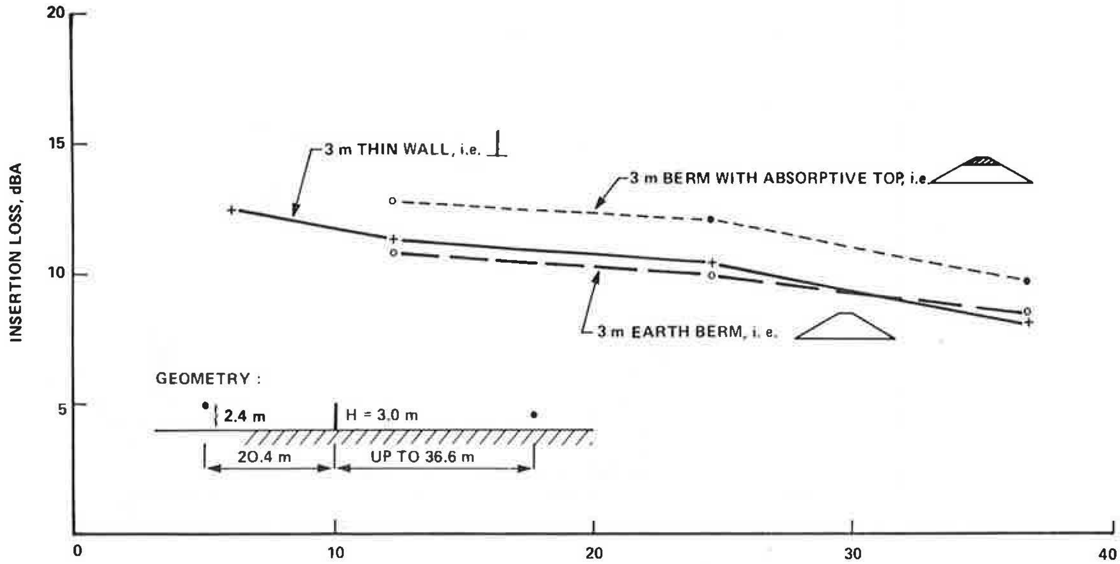


Figure 9. Effect of mounting thin-wall atop 3-m-high earth berm.

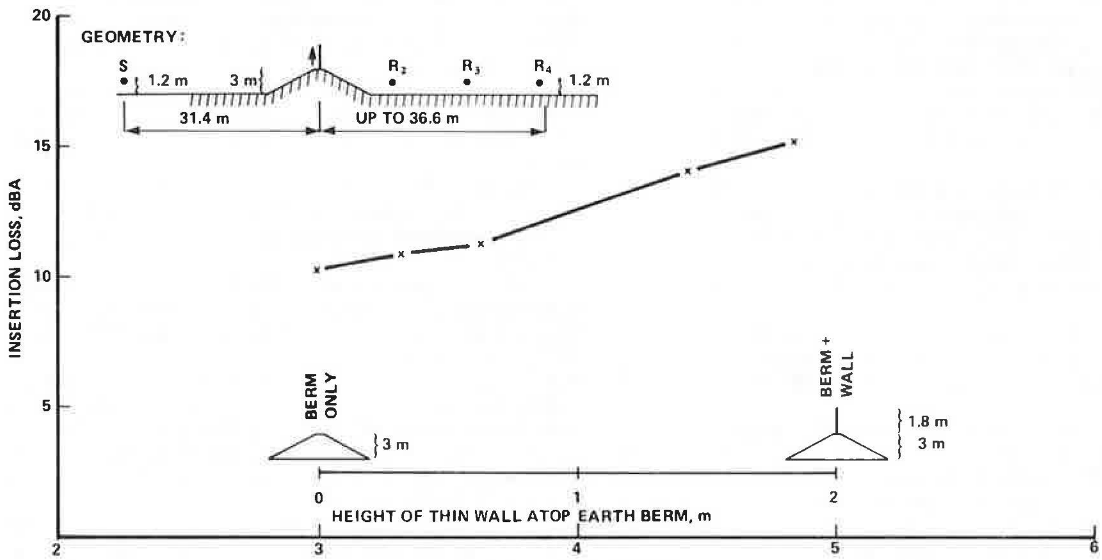


Figure 9 shows that insertion loss increased with the increased height of the thin-wall barrier atop the earth berm. The insertion loss shown is average for 12.2, 24.4, and 36.6 m behind the barrier (the source is in the fifth lane, as shown in Figure 4). The rate of increase in insertion loss was not quite uniform, being somewhat lower initially. Nevertheless, the erection of a thin-wall atop an earth berm consistently improved the insertion loss of the earth berm alone.

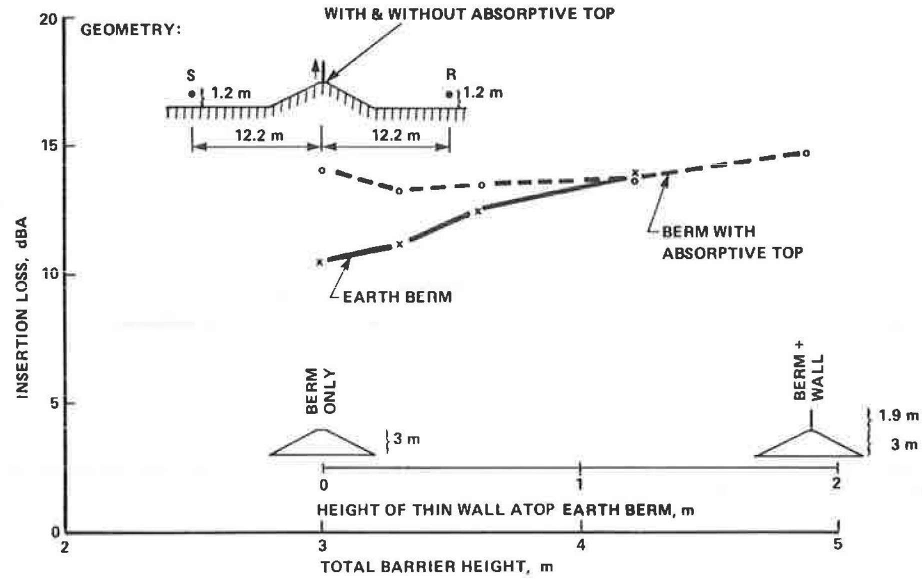
A different picture emerges if the thin-wall is mounted atop the berm with the sound-absorptive top as in Figure 10. (Source and receiver are 1.2 m above grass-covered ground, and the receiver is 12.2 m behind the barrier.) For the geometry used, this structure provides about 3 dB(A) higher insertion loss than its earth berm counterpart. Mounting a thin-wall atop the absorptive-topped berm does not initially increase insertion loss, since the beneficial effect of the absorptive top is lost and is not fully recovered by the increase in the total barrier height. However, as the height of the thin-wall increases to about 1.2 m, the effect of the absorptive top diminishes and the combination of the wall and the absorptive-topped berm and the combined wall and earth berm perform equally.

CONCLUSIONS

The following conclusions, based on the data presented in this paper, are intended mainly to stimulate interest in the relative acoustical performance of the two most common barrier shapes: reflective thin-walls and earth berms.

1. Reflective thin-walls, earth berms, and the

Figure 10. Effect of mounting thin-wall atop earth berm with sound-absorptive top.



combination of the two are about equally effective (in terms of insertion loss) provided the berm is covered by grass or similar material. Actually, for the majority of source-barrier-receiver geometries investigated in the scale-model study, a slightly lower insertion loss [usually less than 1 dB(A)] was measured for earth berms than for thin-walls of the same height. This difference may not have practical significance since it also depends on the sound-absorptive properties of the material used to model the grass-covered ground.

2. The acoustical performance of an earth berm can be increased by placing sound-absorptive material on its top. On the other hand, placing bicycle paths or walkways on earth berms that serve as noise barriers would make the top reflective and should be avoided.

3. The erection of relatively low thin-walls atop earth berms is acoustically justified since it increases the insertion loss beyond that of earth berms alone.

4. Research on the effect of barrier shapes should be continued, and full-scale testing should be emphasized. An improvement of several dB(A) attributable to barrier shape may be considered significant since the insertion loss provided by barriers in the field is usually in the 5- to 10-dB(A) range.

REFERENCES

1. J.K. Manhart. Engineering Guidelines for Highway Noise Shield Design. Transportation Engineering Journal, ASCE, Vol. 100, No. TE4, Nov. 1974, pp. 909-919.
2. R.E. Halliwell and J.D. Quirt. Traffic Noise Prediction. National Research Council of Canada, Ottawa, Building Research Note 146, 1979.
3. Calculation of Road Traffic Noise. Welsh Office, U.K. Department of the Environment, London, July 1975.
4. T.M. Barry and J.A. Reagan. FHWA Highway Noise Prediction Model. Office of Research, FHWA, Rept. No. FHWA-RD-77-108, Dec. 1978.
5. D.N. May. Ontario's Highway Noise Barrier Research. Proc., Inter-Noise '80, Miami, Dec. 1980, pp. 571-574.
6. M.E. Delany, A.J. Rennie, and K.M. Collins. Scale Model Investigations of Traffic Noise Propagation. U.K. Department of Trade and Industry, London, NPL Acoustics Rept. AC 58, Sept. 1972.
7. H.G. Jonasson. Diffraction by Wedges of Finite Impedance with Application to Depressed Roads. Journal of Sound and Vibration, Vol. 25, No. 4, 1972, pp. 577-585.
8. A.D. Pierce. Diffraction of Sound Around Corners and over Wide Barriers. Journal of Acoustical Society of America, Vol. 55, No. 5, 1974, pp. 941-955.
9. W. Porada. Model Measurement of Noise Screening of Line Sources by Single and Double Barriers. Applied Acoustics, Vol. 8, 1975, pp. 271-280.
10. R.G. Cann. Scale-Model Study of Los Angeles International Airport. Transportation Engineering Journal, ASCE, Vol. 101, No. TE3, Aug. 1975, pp. 455-462.
11. M.A. Simpson. Field Evaluation of Highway Noise Control Structures. Proc., Inter-Noise '76, Washington, DC, April 1976, pp. 325-328.
12. M. Ringheim. Traffic Noise Attenuation by Wide Screens. Proc., Inter-Noise '76, Washington, DC, April 1976, pp. 321-324.
13. E.S. Ivey and G.A. Russel. Acoustical Scale-Model Study of the Attenuation of Sound by Wide Barriers. Journal of Acoustical Society of America, Vol. 62, No. 3, 1977, pp. 601-606.
14. S.I. Hayek, J.M. Lawther, R.P. Kendig, and K.T. Simowitz. Investigation of Selected Noise Barrier Acoustical Parameters. Applied Research Laboratory, Pennsylvania State Univ., University Park, Final Rept., April 1978.
15. D.N. May and M.M. Osman. Highway Noise Barriers: New Shapes. Journal of Sound and Vibration, Vol. 71, No. 1, 1980, pp. 73-101.
16. L. Nijs. Combined Effects of Ground Absorption and Diffraction by Obstacles. Proc., Inter-Noise '80, San Francisco, Dec. 1980, pp. 545-548.
17. R. Seznec. Diffraction of Sound Around Barriers: Use of the Boundary Elements Technique. Journal of Sound and Vibration, Vol. 73, No. 2, 1980, pp. 195-209.
18. J.M. Lawther, S.I. Hayek, D.C. Tate, and M.A. Nobile. Theoretical and Experimental Investigations of Selected Noise Barrier Acoustical Parameters. Applied Research Laboratory,

Pennsylvania State Univ., University Park, Final Rept., Feb. 1980.
19. M. Ringheim. Traffic Noise Attenuation by Screens: Preliminary Investigation of Model-Test Techniques. Norwegian Institute of Technology, Trondheim, Rept. LBA335, 1971.
20. D.N. May and M.M. Osman. The Performance of Sound Absorptive, Reflective, and T-Profile Noise Barriers in Toronto. Journal of Sound and Vibration, Vol. 71, No. 1, 1980, pp. 65-71.
21. L.S. Wirt. The Control of Diffracted Sound by Means of Thnadners (Shaped Noise Barriers). Acoustica, Vol. 42, No. 2, 1979, pp. 73-88.
22. A.D. Rawlins. Diffraction of Sound by a Rigid Screen with an Absorbent Edge. Journal of Sound and Vibration, Vol. 47, No. 4, 1976, pp. 423-541.
23. G.F. Butler. A Note on Improving the Attenuation Given by a Noise Barrier. Journal of Sound and Vibration, Vol. 32, No. 3, 1974, pp. 367-369.
24. E.J. Rickley, U. Ingard, Y. Cho, and R.W. Quinn. Roadside Barrier Effectiveness: Noise Measurement Program. Office of Research and Development, U.S. Department of Transportation, Rept. HS-803-289, April 1978.
25. M.D. Harmelink and J.J. Hajek. Evaluation of Freeway Noise Barriers. TRB, Transportation Research Record 448, 1973, pp. 46-59.
26. J.J. Hajek. Noise Barrier Attenuation: Highway 401 North Side East of Avenue Road, Toronto. Research and Development Division, Ontario Ministry of Transportation and Communications, Downsview, Rept. 80-AE-03, Aug. 1980.
27. M.M. Osman. MTC Scale-Model Facility for Transportation Noise Problems: Instrumentation Manual. Research and Development Division, Ontario Ministry of Transportation and Communications, Downsview, Rept. 77-AC-03, June 1977.
28. M.M. Osman. MTC Scale-Model Facility for Transportaton Noise Problems: Materials Choice and Validation for Scale-Modeling. Research and Development Division, Ontario Ministry of Transportation and Communications, Downsview, Rept. 77-AC-04, June 1977.
29. T. Isei, T.F.W. Embleton, and J.E. Piercy. Noise Reduction by Barriers on Finite Impedance Ground. Journal of Acoustical Society of America, Vol. 67, No. 1, Jan. 1980, pp. 46-58.

Publication of this paper sponsored by Committee on Instrumentation Principles and Applications.

Quality Control for Environmental Measurements

EARL SHIRLEY

A general overview of the quality assurance program for environmental measurements practiced by the California Department of Transportation is presented to illustrate current practice. The discussion, which is general rather than detailed, places the program in perspective and concentrates on equipment used to measure noise and air pollutants and the associated instrumentation and procedures for calibration. A quality assurance program is necessary to ensure the validity and reliability of environmental measurements. Traceability of instrument calibration to an authority such as the National Bureau of Standards is important. The program involves fairly complex instrumentation systems and requires expert technical personnel and good documentation.

One of the fundamental responsibilities of management is the establishment of a continuing program to ensure the reliability and validity of any measured test value. The California Department of Transportation (Caltrans) has been following such a program for a number of years to provide assurance that test data involving materials such as asphalt, soils, and concrete are valid. To achieve this, the department has been participating in national programs sponsored by organizations such as the American Society for Testing and Materials, the Materials Reference Laboratory of the American Association of State Highway and Transportation Officials, and the Cement and Concrete Reference Laboratory of the National Bureau of Standards (NBS) and has been carrying out its own quality control program.

The addition of environmental testing responsibilities to Caltrans' normal duties brought about a need for a quality assurance program (QAP) in those areas also. Specifically involved were test data relating to air quality, water quality, and noise and vibration. Some of the benefits that would result from such a program were seen to be

1. Increased confidence in decisions based on environmental data;
2. A solid, defensible position in the event of litigation involving environmental data;
3. Uniformity in techniques and procedures for the use of instruments and their calibration and for data analysis; and
4. Unqualified acceptance of Caltrans test results by other organizations.

With the need for a QAP identified, it was necessary to decide on the program type and scope that would best fit Caltrans needs. Three basic alternatives were examined:

1. Develop a full "standards laboratory" capability in-house,
2. Make use of equipment manufacturers' regional service centers, or
3. Develop an in-house capability similar to that of a manufacturer's regional service center.

The first alternative was judged to be too costly. For example, the noise portion would require either the rental or the construction of an anechoic chamber. It was also felt that full-scale testing of environmental measurement equipment in accordance with American National Standards Institute, U.S. Environmental Protection Agency (EPA), and NBS procedures was neither cost effective nor necessary for Caltrans operations.

The second alternative, based on previous experience, would lead to long "turn-around" times (up to three months) and tend to discourage regular calibration. In addition, since most of the regular