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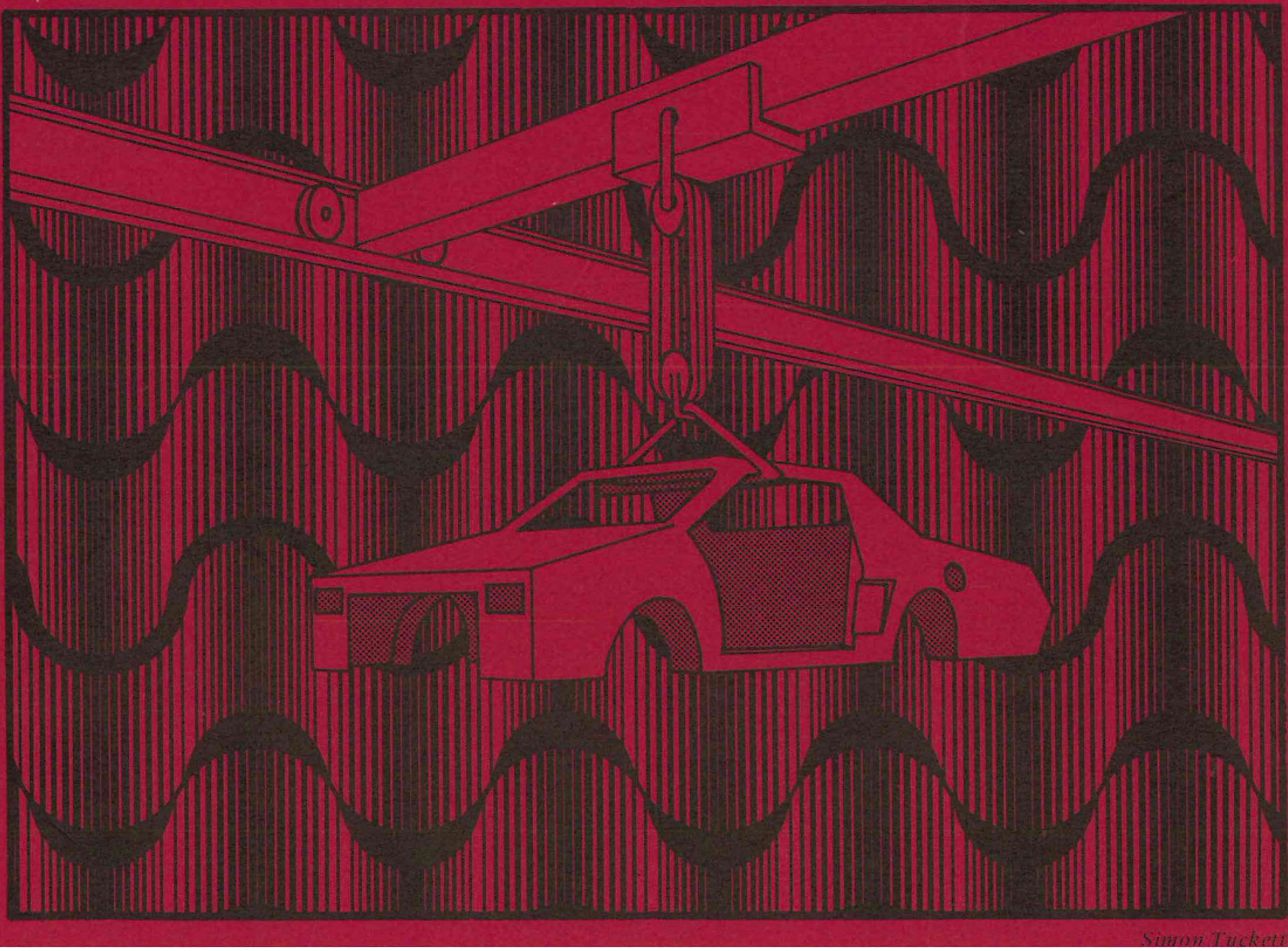
acoustics and noise control in canada

JANVIER, 1980
Vol. 8, Nº 1

l'acoustique et la lutte antibruit au canada

Our cover illustrates the article starting on page 4.



Simon Tuckett

acoustics and noise control in canada

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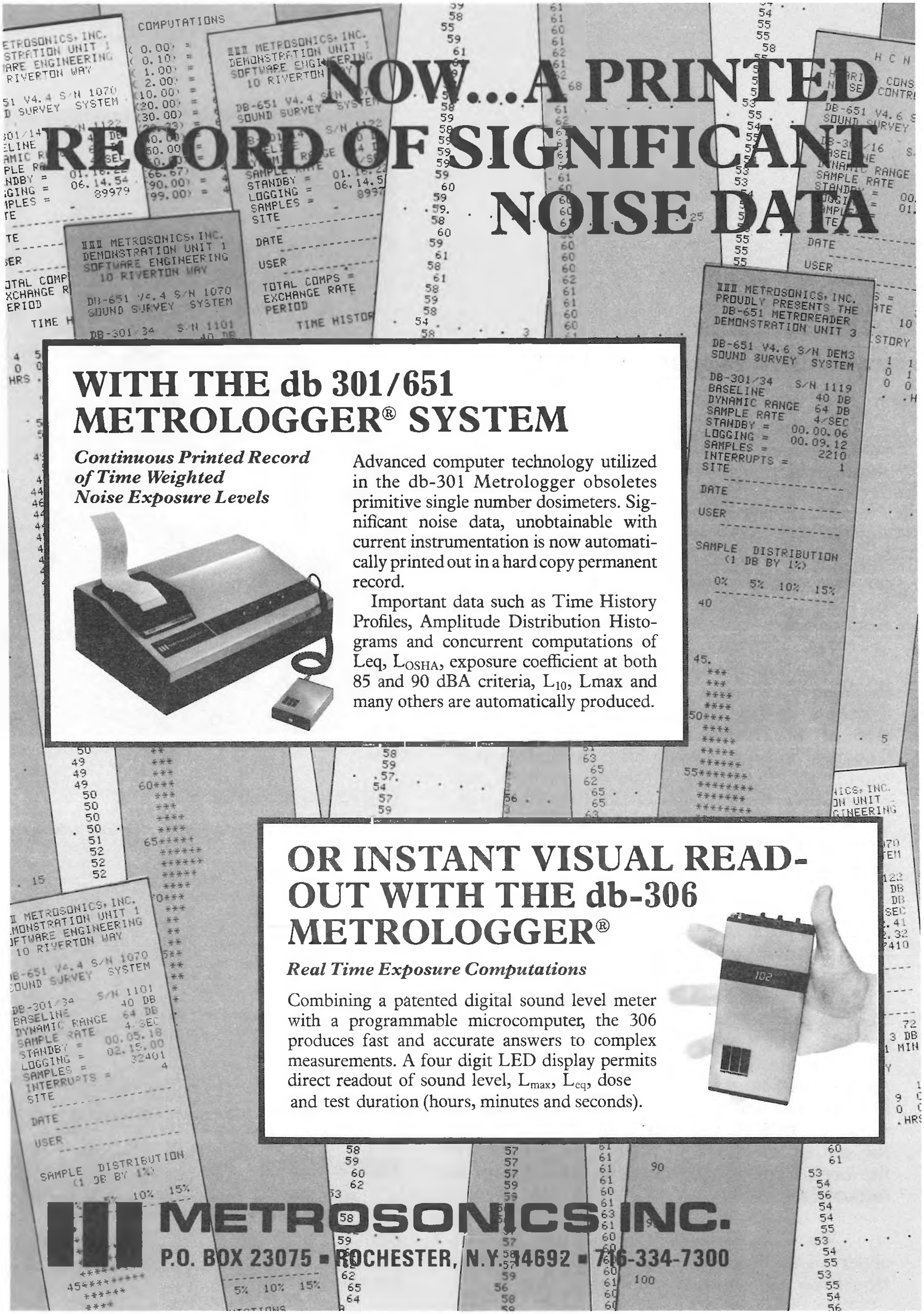

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TOM NORTHWOOD - CAA's NEW PRESIDENT

We take pleasure in reporting the election of Dr. T. D. Northwood as President of the Canadian Acoustical Association.

It is fitting that the man who was founder and first Chairman of the CAA (or as it was then called, the Canadian Committee on Acoustics) should again head the Association as it enters a new phase of its development.

Tom Northwood received his BASc in Engineering Physics from the University of Toronto. In 1940 he joined the Physics Division of the National Research Council of Canada, working principally in underwater sound. In 1952, after obtaining his Ph.D., he returned to the Division of Building Research of NRC, where he has since headed a group working in building acoustics and structural dynamics.

Tom is a Fellow of the Acoustical Society of America and the American Association for the Advancement of Science, a member of the Engineering Institute of Canada, and an initial member of the Institute of Noise Control Engineering. He has served in many capacities in these societies, and is currently an associate editor of the Journal of the Acoustical Society of America. He is active in standards work, in ASTM Committee E33, ANSI S1, ISO/TC 43, and CSA Z107. He is the author of about 50 papers and editor of the book Benchmark Papers in Architectural Acoustics.

We look forward to continued growth under his guidance and are confident that the transition will be smooth and effortless.

SUSTAINING SUBSCRIBERS

At the CAA's last business meeting, a decision was made to impose a first-ever membership fee of $10 per annum. The $10 is partly to pay for each member's copies of "Acoustics & Noise Control in Canada," which had formerly been distributed free.

Certain individuals had, however, already felt that they wished to contribute $10 toward the magazine - these are the individual Sustaining Subscribers listed on the back of recent issues. As a mark of appreciation for their voluntary support, the magazine has now arranged for their donations to be credited to the membership fee account, making them exempt from 1980 dues.

As a result of this transfer, the back cover of this and future issues will contain only the names of organizational Sustaining Subscribers contributing a considerably higher sum, now $85.

INTERNOISE '80

Internoise '80 is scheduled for December 8-10, 1980 at the Hotel Intercontinental in Miami, Florida. Contributed papers are invited: please send abstracts by May 12, 1980 to James G. Seebold, Technical Program Chairman, INCE, P. O. Box 3206, Arlington Branch, Poughkeepsie, NY 12603.

SAE'S 75TH ANNIVERSARY

The Society of Automotive Engineers will hold its 75th Anniversary Congress and Exposition in Detroit in the last week of February 1980. The conference includes a number of noise-related sessions, including an all-day one on "Vehicle Noise Regulation & Reduction" scheduled for Wednesday, February 27 in Room 3042, Cobo Hall.

In addition to a number of American authors, Canadian authors include J. E. Piercy and T. F. W. Embleton ("Noise Testing of Vehicles: Acoustic Propagation Phenomena"); E. R. Welbourne and D. S. Kennedy ("A Comparison of Two Stationary Measurement Procedures for Truck Exterior Sound Levels"); Z. Reif ("Noise Exposure of Truck Drivers"); and M. M. Osman and D. N. May ("Relative Influence of Pavement Texture and Tire Type on Pavement/Tire Noise").

The meeting will be chaired by Edgar Rose, Director of Stern Drive & Accessory Engineering, Outboard Marine Corporation; Assistant Chairman is Dr. Moustafa Osman, Ontario Hydro. The combined proceedings of the 1980 and 1978 papers from these sessions will be issued by SAE as Special Publication 456 ($18 to members, $22.50 to non-members, in U.S. funds).

Daryl May will be presented with a Certificate of Appreciation by SAE's Engineering Activity Board, February 26, for chairing and organizing the 1978 session, and co-organizing the 1980 one.

ACOUSTICS WEEK IN MONTREAL

Preliminary details of an acoustics week to be held in Montreal October 20-25, 1980 are as follows:

(1) Seminar on "Occupational Exposure to Noise and Vibration: Effects, Measurements and Control." Jointly organized by National Research Council and Health & Welfare Canada (October 20-21),

(2) Canadian Acoustical Association Annual Meeting and Symposium (October 22-23),

(3) Canadian Standards Association Annual General Meeting (October 24).

Further details will be announced in a subsequent issue.

MONTREAL: SEMAINE DE L'ACOUSTIQUE

Nous avons reçu l'avis suivant sur "la semaine de l'acoustique," que aura lieu à Montréal du 20 au 25 octobre, 1980:

(1) Colloque sur "L'exposition professionnelle au bruit et aux vibrations: ses effets, son évaluation et son contrôle." Organisé conjointement par le Conseil Nationale de Recherches, et Santé et Bien-être Social Canada (les 20 et 21 octobre),

(2) Symposium et réunion annuelle de l'Association Canadienne de l'Acoustique (les 22 et 23 octobre),

(3) Assemblée générale annuelle de l'Association Canadienne de Normalisation (le 24 octobre).

D'autres details paraîtront dans la prochaine issue.

NOISEXPO '80

Noisexpo '80 is scheduled for April 28-May 1, 1980 at the Hyatt Regency O'Hare, near Chicago's O'Hare Airport. The conference emphasis is on noise and vibration control technology. Contributed papers are invited. Please send your name, address, phone, paper title, paper author names, and a summary, to Program Coordinator, Noisexpo, 27101 E. Oviatt Road, Bay Village, Ohio 44140.

ALBERTA'S NOISE REPORTS

The first of two volumes of "Noise in the Human Environment" has been issued by the Environmental Council of Alberta, 8215-112 Street, Edmonton, T6G 2M4. This first volume is a 120-page report on community noise from a planning standpoint. It contains six chapters on noise in a Canadian context, with Alberta's needs obviously addressed first. The second volume discusses noise more generally.

Both volumes are edited by Professor H. W. Jones, Physics Department, University of Calgary. Hugh Jones organized the team of authors, referees and consultants who prepared the report for the Environment Council. Most of the contributors came from the ranks of the Canadian Acoustical Association, using only minimal Alberta government funding for essential expenses. The reports are therefore noteworthy for the dedication exhibited by the editor and contributors in serving the public with their expertise.

It is unfortunate, perhaps, that the Environment Council's foresight in sponsoring this work has so far been followed by such caution in making use of the product. In his Preface to the first volume, the Chief Executive Officer of the Council not only makes the usual official disclaimer of agreement with the authors' views; he states that he will see how the public reacts to the report before deciding the next step. The next step? - he will recommend public hearings throughout the province to decide what to do about noise.

NEW RESEARCH CONTRACTS

We are grateful to Past-President Bill Bradley for keeping us posted on the latest research contracts awarded by the federal government:

To Sherbrooke University, Quebec (Dr. J. P. Adoul), $19,935 for "Transmission and digital processing of spoken information - phase II." Awarded by Dept. of Communications.

To Geomarine Associates Ltd., Halifax, N.S., $4000 for a "Study on the acoustic target strength of pingo-like features found in the Beaufort Sea." Awarded by Dept. of Fisheries and Oceans.

To Heathwood Engineering Associates Ltd., Kirkland Lake, Ontario, $32,837 for a "Study on noise reduction of diamond drilling equipment." Awarded by the Dept. of Energy, Mines and Resources.

To Bell-Northern Research Ltd., Ottawa, $92,897 for "Development of the normalization of speech for automatic recognition." Awarded by the Dept. of National Defence.

NOISE CONTROL IN THE AUTOMOTIVE INDUSTRY: SOME PRACTICAL EXPERIENCE

Mohan Barman, M.A.Sc., P.Eng.

Vibron Limited
Mississauga, Ontario

ABSTRACT

The General Motors Transmission Plant in Windsor, Ontario is presently undergoing a large-scale expansion program. This program has included a commitment by management to meet all appropriate sound and vibration criteria related to in-plant, office and environmental acoustics. The consequence of this decision is that substantial expenditures will be allocated for noise and vibration control. The following paper presents some aspects of a noise and vibration control program generated to ensure adequate control of cost and performance of the acoustical materials and hardware being considered. Also discussed are methods developed to deal with the practical problems of meeting acoustical design targets in a major industrial plant and results obtained to date.

Both to meet noise regulations and to reduce hearing loss, 85 dBA was selected as the maximum in-plant noise goal. A better working environment with enhanced productivity was considered an offshoot of the design goal.

The noise control design of a new plant is best carried out from a proposed layout and equipment list. In this case, the GM plant expansion has evolved as corporate decisions and targets have changed, so noise control methodology had to be flexible. To start with, some general acoustic treatments of the plant at construction were considered.

A typical example is the separation of noisy areas from quiet areas using barrier walls. For precise cost-benefit analysis, computer assisted noise maps, with or without acoustic treatment, were originally proposed. However, for the want of definitive layout and equipment lists, the acoustic treatment of walls and ceilings were decided on the basis of past experience, subjective judgement and knowledge of the type of equipment slated for the plant areas of concern.

The main thrust of the plant noise control is, however, built around the machine tools and other equipment to be purchased for this plant. In theory, the procedure is clear cut: the owner writes a noise specification for the equipment and the vendor complies. In practice, a host of problems are encountered. For example, the owner may not have an enforceable noise specification and may not have a mechanism to enforce it. The vendor, on the other hand, may not take the specification seriously or may not know how to meet the specification.

Based on past experience, it was decided to meet the problem head on and make the best use of the noise specification. A more active role was decided on to help the supplier meet the requirements of the noise specification such that problems would not be encountered near delivery deadline time.

The role was considered to be noise Quality Assurance (QA), similar to an engineer's role in building construction, as an owner's representative. To carry out this role successfully, three ingredients were necessary:

(a) First, an enforceable noise specification that is clear in intent and covers most possibilities. This is true of the GM specification which generally calls for 80 dBA when measurement is taken according to NMTBA or other standards.

(b) A good certification and acceptance scheme built into the contracts and the purchase order is equally important. Vibron has worked with QA schemes where monitoring was the only role, since the contracts were based on performance after installation. It needed co-operation from the supplier for the QA to be effective. The co-operation was not forthcoming in some instances, and the equipment failed to meet noise specification after installation, creating an additional difficulty for the equipment purchaser.

(c) Third, it also requires a good deal of perseverance and a firm commitment on the part of the purchaser.

All three ingredients were present in the GM example and a QA procedure was established as follows:

(i) Contact bidder and suppliers

(ii) Obtain noise output data of identical or similar machines during actual operation--either from the supplier or from independent measurements

(iii) If the machine does not or is not likely to meet noise specifications, a noise control program is insisted upon. One or more meetings may be arranged with the manufacturer to review in detail all the noise control measures that are possible

(iv) The manufacturer is advised to hire outside experts if necessary. In extreme cases, the supplier may be offered the help of GM and Vibron

(v) An internal policy is instituted at the GM Windsor Transmission Plant, whereby no machine is accepted without noise QA approval

The QA procedure above produced two immediate benefits:

(a) It was possible to persuade a number of apprehensive manufacturers that they were capable technically, to meet GM noise specification.

(b) A closer scrutiny was made of the noise control hardware of a number of bidders and a considerable cost saving was pointed out.

One machine tool builder had used expensive in-house labour to erect sheet metal enclosures but the large number of doors in the enclosure had no seals whatsoever. The manufacturer was steered to a local sheet metal contractor proficient in similar work, with both saving in cost and increase in the effectiveness of the enclosure.

Another machine tool builder was insistent that 80 dBA was impossible. When a meeting was arranged and all the noise producing mechanisms were discussed in detail, the manufacturer agreed that solutions suggested are feasible. They hired an outside consultant to treat the noise sources and have indicated the likelihood of meeting GM specification.

It has been quite customary to find machine tool builders preparing enclosure designs with little knowledge of good noise control practices. One finds absorptive materials covered with heavy plastic lining, doors with no seals and enclosures attached rigidly to vibrating surfaces. It is equally common to find large, untreated openings at the wrong kind of places. At the other extreme, one manufacturer offered a 20 dB enclosure at enormous cost, to solve a 3 dB problem.

One other common and persistent problem has been the efforts made by the machine tool builders to avoid taking responsibility for machining noise. The GM noise specification is very specific about this, and has gone as far as to simulate a loading method for the presses for noise certification.

It has often been said that noise control at the source has been sorely missing in the industrial workplace. This is one way in which we have found that the manufacturers can be made to look at noise control of the equipment that they provide.

In the past, even the most well-intentioned plans for noise control for new plants were severely hampered by equipment manufacturers' failure to include noise control as one of their priority features. GM plans for a noise control program have managed to overcome some of these difficulties and with supporting professional expertise, encourage manufacturers to comply with noise control specifications, resulting in a more desirable workplace environment.

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Since the concentration of workers around this equipment is also high, it is essential that workers be protected from hearing loss due to noise exposure. The post office decided on the most stringent levels of 70 dBA in manual sorting areas, which affects the majority of workers, 75 dBA in other areas and 80 dBA as the absolute maximum anywhere. After initial planning and projected noise maps, it became clear that only by working with the process equipment suppliers was it possible to meet the goals. The term noise QA (quality assurance) was invented and tests were devised for prototype equipment. Noise control features were recommended to the equipment manufacturers and incorporated in the prototype testing in successive stages.

The final stage of commissioning of process equipment is taking place at present. While most process equipment meets the noise QA standards, some production versions require fine-tuning in the field.

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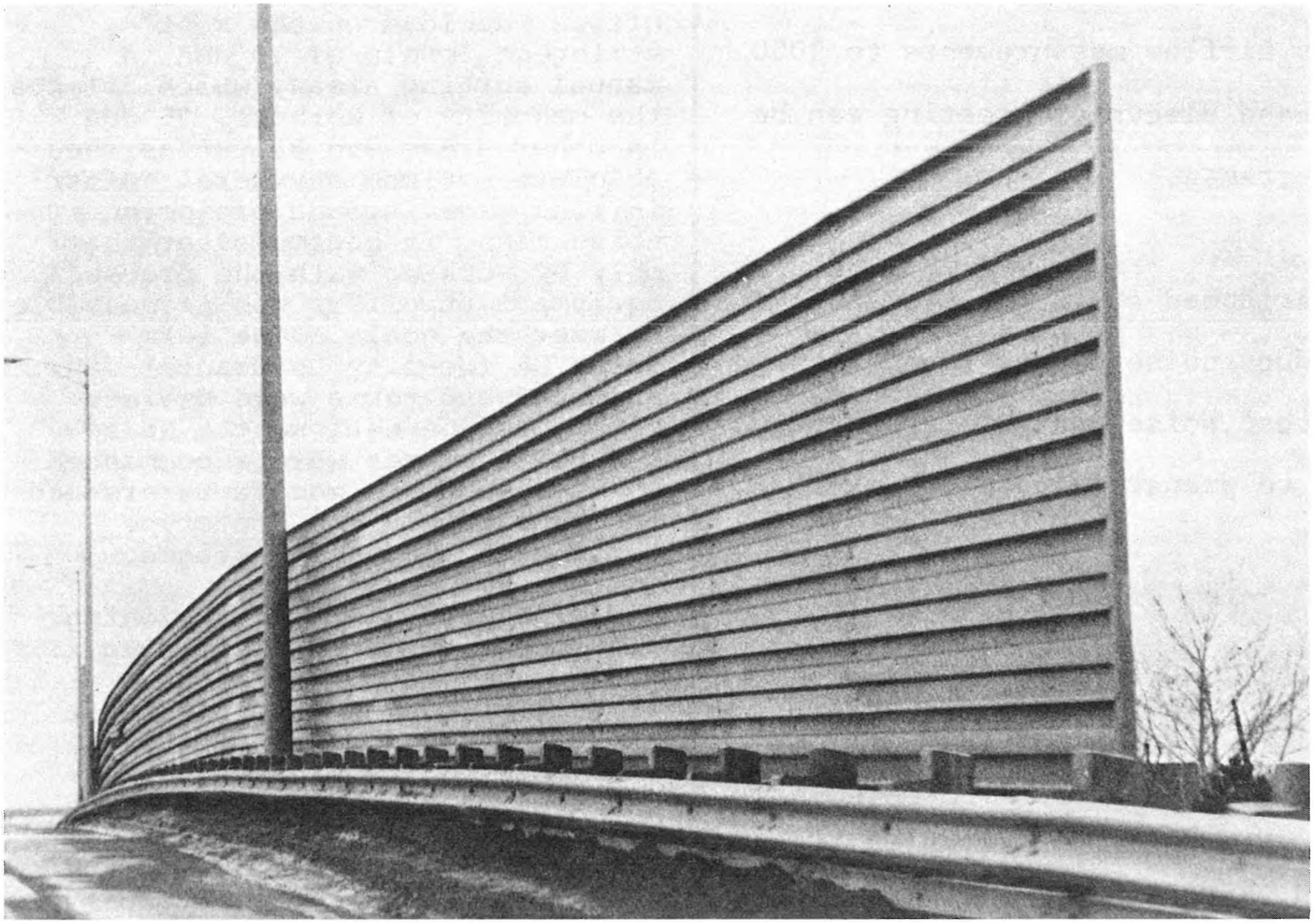
ONTARIO'S HIGHWAY NOISE BARRIER RESEARCH

Daryl N. May*
Wyle Laboratories
128 Maryland Street
El Segundo, California 90245

Ontario's Ministry of Transportation and Communications (MTC) has been involved in a highway noise R&D and implementation program to quieten the provincial freeway system in residential neighborhoods.

The program primarily involves noise barriers and pavement, because these two items are within provincial control. (The federal government regulates new vehicle noise.) The barrier construction program now has a $7.5m budget, making it probably the largest Canadian noise control program.

Ontario received this new impetus to its noise program as recently as 1975, when MTC called together representatives of the



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*This work was performed while the author was in charge of noise research at the Ministry of Transportation & Communications, Ontario.

Ministries of Housing and Environment, and set up a committee (chaired by the author) to develop noise standards for freeways in residential areas.

With subsequent Cabinet endorsement, the committee's work became a major ingredient in Ontario's residential noise standards, which in this context essentially involve:

o MTC responsibility for freeway noise control where adjacent residential development precedes the freeway,

o Ministry of Housing responsibility (exercised with the advice of Ministry of Environment) for residential noise control where residential development postdates the freeway.

This paper reviews the major R&D and implementation achievements of the first, i.e., MTC, area of responsibility, with an emphasis on its noise barrier aspects. It has become clear from discussions and letters received in performing this work that other provinces and many American states have similar goals, and that our own contributions interested them. However, it was also clear that we had sometimes been too busy actually doing the work to share it. This paper's overview therefore emphasizes the publications available in the general literature or as MTC internal reports. (The latter are free from the Technology Transfer Office, R&D Division, MTC, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8.)

MTC has researched barriers mainly as systems, emphasizing study of their optimum location, height, thickness, shape and materials, and verifying their acoustic and perceived benefits. These studies have been directed at improving the benefit/cost of the province's barrier construction program. Because of the large capital expenditures when highway barriers are constructed "by the mile," a relatively minor R&D expenditure can produce a big payoff. In approximate terms, MTC's $250,000 barrier R&D investment may have increased by 33 percent or more the benefits from the current $7.5m allocated for construction, which is equivalent to a 10:1 return on the research outlay. This ratio will improve further if, as seems likely, the construction budget is increased.

Although this paper emphasizes the R&D aspects of the program, some useful background reading on its administrative and construction aspects is in:

"Proceedings of Noise Barrier Seminar," Report 78-AC-16, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1978.

The above report describes the different approaches taken for existing freeways ("retrofit" barriers) and new freeways ("new construction" barriers), and deals with the adoption of standard designs, contract awards, landscaping, construction, maintenance and monitoring of the overall program, and gives a brief overview of the acoustical aspects.

1. Site Selection

There are two obvious phases in deciding barrier "placement": first you choose the site (as described here), then you choose the barrier for each site (see Section 2). These phases are not entirely separate, however, because it is necessary in analyzing a site's suitability to see how a barrier might perform there.

As part of the site selection process, MTC ranked over 100 sites across the province for the benefit/cost of the barriers that might be installed at each. This process involved:

o a preliminary determination of barrier length, alignment within the right-of-way, and height

o a benefit/cost model

o a computer prediction of "before and after construction" sound levels

o estimate of costs

o benefit/cost calculation for each site.

At this, the site selection phase, the determination of barrier length, alignment and height need only be preliminary. Barrier length was established by "eyeballing" the roadway and adjacent residences, terminating the barrier at a point beyond the limits of the more dense residential development; invariably this termination occurred at an "on" or "off" ramp. Barrier height was determined by calculating the predicted benefit/cost at a number of potential sites for barrier heights ranging from about 8 ft to 25 ft. The optimum barrier height from these calculations was 13 ft, which was also sufficient to satisfy our "minimum attenuation" criterion of 5 dB(A). The site selection process then used heights of 13 ft and 10 ft to show up any sites for which barrier height was so sensitive a determinant of performance that yet other heights should be considered.

Barrier alignment was determined by a parametric study, in which barriers were located variously at the highway edge-of-shoulder, right-of-way line, and an intermediate point. The relative elevations of highway, adjacent residences, and intermediate terrain were varied, and the calculations were performed for narrow and wide highways. One of the sets of geometries explored is shown in Figure 1.

The study concluded that:

o for flat terrain, or terrain in which the roadway and receivers are equally elevated but separated by a ditch or other depression, the best barrier location is near the receiver, i.e., near the residences

o for roadways raised above the right-of-way by 4 ft or more, the best barrier location is probably near the highway, but this should be verified by detail design

o for a depressed roadway, the best barrier location is near the receiver

o for terrain in which the roadway and receivers are separated by more elevated terrain, barrier location must be studied in detail. For elevations of the intermediate terrain that exceed the grade elevation by 2 ft or so, the best barrier location may be the raised intermediate point.

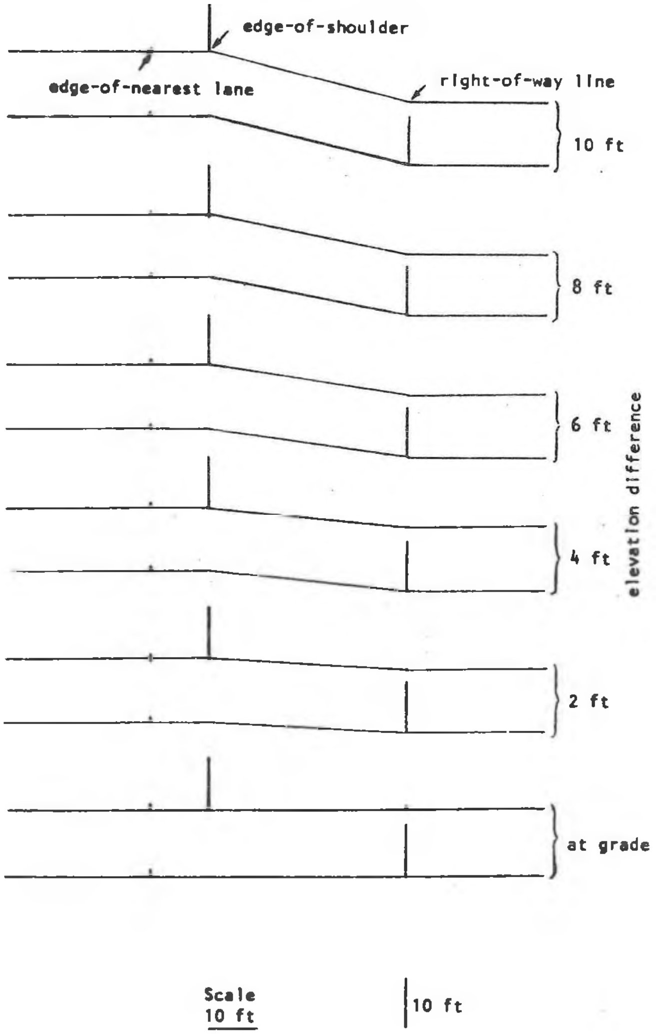


Figure 1. An example of some geometries investigated in a parametric study to preliminarily determine the best location of a barrier for site selection purposes. (For origin, see Section 1.)

Using these principles and an FHWA prediction program, sound levels were calculated outside the residences of representative homes up to several hundred feet from the highway - for all the sites, first without a barrier, then with a barrier of each of the two heights considered. The task was a major one, involving digitizing all relevant heights to take account of the three-dimensional features of the terrain. (Neglect of this can introduce large errors whenever elevations change.)

Together with cost estimates provided by the Highway Design Office, these sound levels were inputted to an MTC computer program to calculate benefit/cost. Benefit, in this instance, was modeled to consider

o the predicted barrier noise reduction at each home,

o the amount by which the without-barrier sound level exceeded a criterion sound level at each home, and

o the number of homes.

The ranking of candidate noise barrier sites by their predicted benefit/cost provides administrators with an objective way to allocate construction funds. They are then more able to resist the more influential, but not necessarily the most noise barrier-deserving residential pressure groups. The result also dilutes the tendency for the government in power to allocate construction on a political basis. By these means, a greater degree of benefit is achieved per dollar.

The most convenient references to this work are the one indicated in the introductory paragraphs, and:

C. Andrew and D. N. May, "Highway Noise Barrier Location for Maximum Benefit/Cost."

(1) Report 78-AC-03, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1978.

(2) To be published, J. Sound Vibration, 1980 (with additional author M. M. Osman).

2. Acoustical Design

The term "acoustical design" here refers to the following geometric aspects of a conventional, i.e., wall barrier, design: height, length and alignment. (Structural aspects and new noise barrier shapes that enhance performance are described later.)

Designing the noise barrier takes place after a site has been selected for construction, and involves studying various options for height, length and alignment to maximize the benefit/cost. The calculation process involves the same computer tools as used for site selection (Section 1), but the process is refined by considering:

o a great many different alignments and lengths, emphasizing those that the regional design office considers most practicable for that site, e.g., from a maintenance or aesthetic standpoint

o every detail of the terrain elevation, which sometimes suggests a barrier should zigzag between the edge-of-shoulder and the right-of-way line to take advantage of local terrain elevation variations

o different heights for different parts of the barrier

o the refined costs of each candidate barrier, including site-specific costs such as to remove guide rail

o the effects on the sound level of different pavement and terrain surfaces

o the presence of any barrier on the opposite side of the highway.

Careful acoustical design on this basis results in fine-tuning the benefit/cost above the value produced in the preliminary site selection analysis. It is also evident in this process what mistakes could have been made without the computer design method: the barrier design options sometimes include a reasonable looking design which might have been selected using traditional, i.e., eyeballing, design methods, but which would perform abominably if it were built. MTC's current approach has so far avoided committing such design to construction.

The best references to this task are those in the introductory paragraphs and in Section 1.

3. New Shapes

The conventional barrier, which is simply a wall, is commonly known to be less effective than a berm of similar height. However no comprehensive investigation has been performed on the many other barrier shapes, i.e., cross-sections, which might also offer performance gains.

To fill this void, MTC developed a scale model facility in which barrier shapes could be easily and inexpensively varied.

Since the materials in a noise scale model facility must exhibit similar absorption coefficients at the model frequencies as the materials they represent do in real-life, a range of locally-available model materials had to be researched. These are described in:

M. M. Osman, "MTC Scale Model Facility for Transportation Noise Problems: Materials Choice and Validation for Scale Modelling," Report 77-AC-4, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1977.

(This work parallels similar studies, using complex impedances, at the University of Calgary and National Research Council, Ottawa.)

The facility was used to explore the performances of the noise barrier shapes shown in Figure 2. In this figure, the circled numbers indicate the improvement in insertion loss exhibited by the various barrier types over that of a conventional barrier. Of particular interest was the fact that T-profile barriers exhibited a performance that was not only better than that of a similar-height conventional barrier, but also better than that of a similar-height, similar-width rectangular cross-section barrier. This is illustrated in Figure 3. It was found that the thickness of the T cap should also be kept as small as possible. To provide an additional performance gain, the top of the T can be treated with a sound absorptive material.

The source-barrier-receiver geometries which generated these results are detailed in the references given below. They occurred in the category of source-barrier-receiver geometry labeled (a) in Figure 4. This is, of course, the most common barrier situation.

The work also investigated other, less common situations: (b) and (c) in Figure 4. A significant "double-barrier degradation" was observed for situation (c), which warned against constructing double barriers, especially on narrow roadways. However, facing the barriers with sound absorptive material

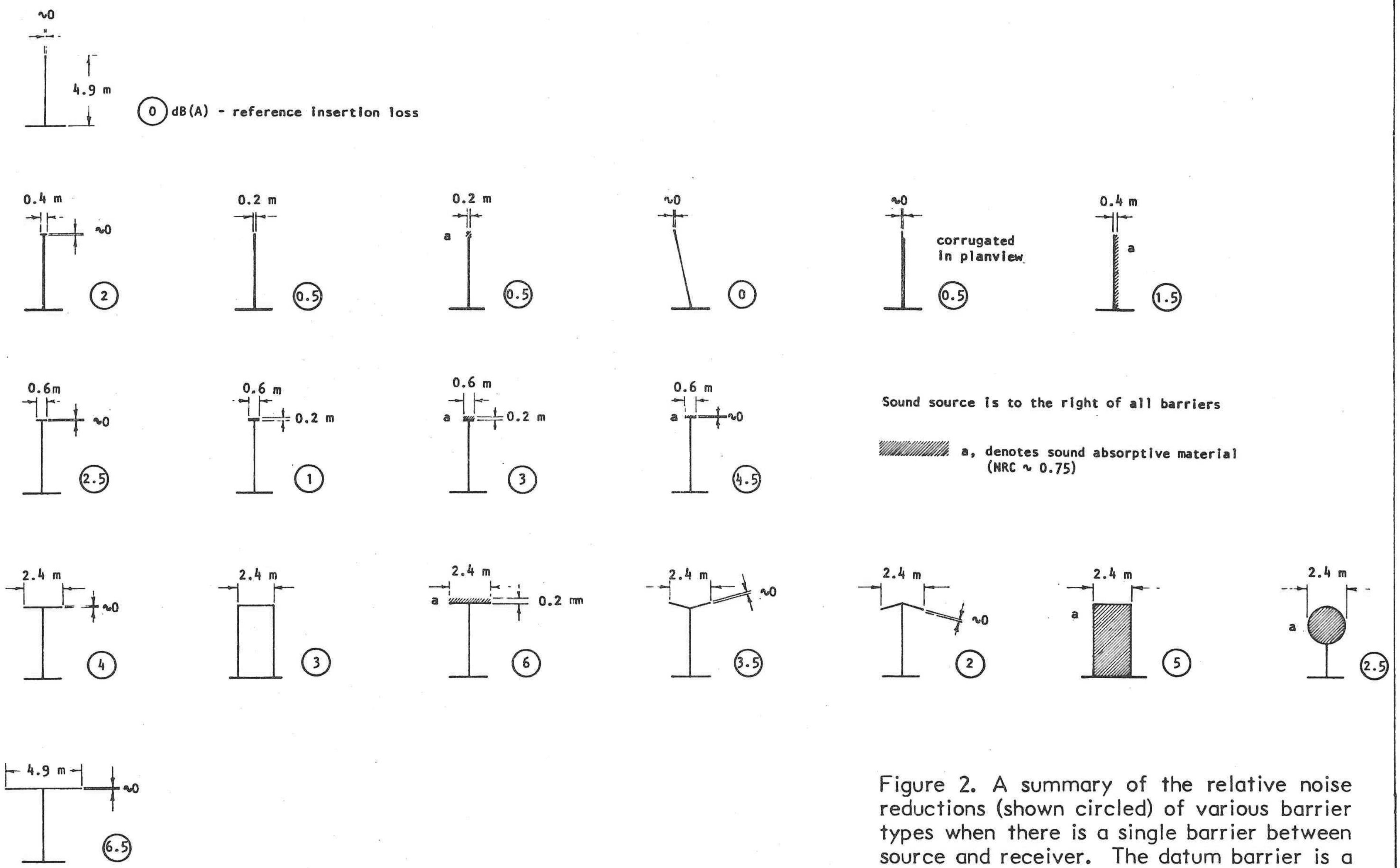


Figure 2. A summary of the relative noise reductions (shown circled) of various barrier types when there is a single barrier between source and receiver. The datum barrier is a conventional, knife-edge top wall given the reference noise reduction here of 0 dB. (From scale model studies, see Section 3.)

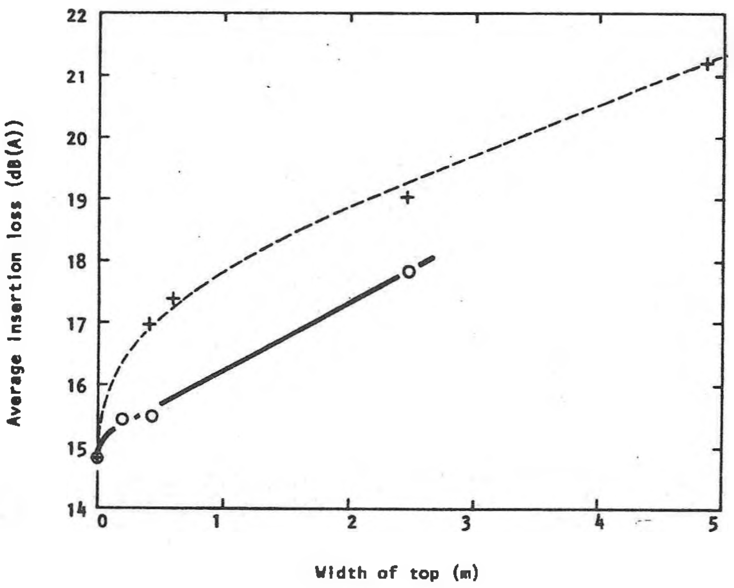
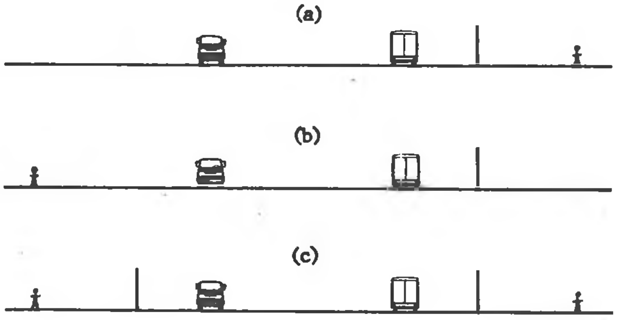


Figure 3. Noise reduction ("average insertion loss") as it varies with the width of top for T-profile barriers in the upper curve, and wide rectangular cross-section barriers in the lower curve. For T-profile barriers with cap widths up to 0.6m (2 ft), the average growth of noise reduction with cap width is 4.1 dB(A)/m. This compares well with the growth rate of 2.0 dB(A)/m as one increases the height of a conventional barrier in a similar test situation. The T-profile barrier may therefore hold promise. (From scale model studies, see Section 3.)

Figure 4. Three source-barrier-receiver situations of relevance.



lessened this degradation. Since this was foreseen from theory, the durability of real-life, i.e, full-scale, materials was simultaneously investigated (see Section 4).

The references to the scale model, noise barrier shape investigations are:

D. N. May and M. M. Osman, "Highway Noise Barriers: New Shapes."

(1) Report 79-AC-06, Research & Development Division, Ministry of Transportation and Communications, Ontario, 1979.
(2) To be published, J. Sound Vibration, 1980.

Full-scale validation of some of these results was also obtained. See the appropriate reference in Section 7.

4. Durability of Sound Absorptive Materials

A wealth of information exists about sound absorptive materials for indoor use, but outdoor use of such materials is fairly rare. To establish the outdoor durability properties of nine types of these materials, MTC ran the following tests:

o The samples were attached for 9 months (through winter) to a wooden noise barrier erected just behind the guide rail of the Queensway freeway in Ottawa

o The sound absorption coefficients of most of the materials were measured before and after the above-mentioned weather exposure, in order to see if there were any significant changes in their values

o Four accelerated durability tests were run in the laboratory.

The results of such studies are, of course, only presentable in considerable length, occupying more space than available here. However, a number of adequately durable materials were found. A full-scale, mile long barrier was constructed in Toronto of one material, made of chemically mineralized and neutralized organic softwood shavings, bonded together under pressure with portland cement.

These results will also be of relevance in other applications, including an MTC-developed use on high-rise balconies (see Section 11.1).

A. Behar and D. N. May, "Durability of Various Sound Absorbing Materials for Highway Noise Barriers."

(1) Report 79-AC-01, Research and Development Division, Ministry of Transportation & Communications, Ontario, 1979.
(2) To be published, J. Sound Vibration, 1980.

continued on page 16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Our Type 7003 four-channel recorder is truly portable — and not just because it weighs only 16 pounds and fits into a brief case. By "portability", we mean that you can take accurate recordings while the instrument is being carried about. A dramatic example of this capability: a snowmobile manufacturer, as part of a test program, stored a B & K 7003 in a rucksack on the driver's back, and took accurate vibration and shock recordings, *while the vehicle was driven across rough open country.*

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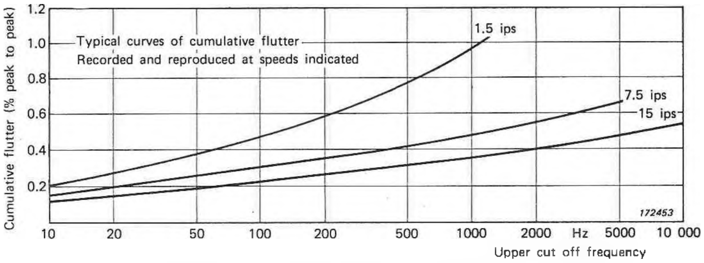
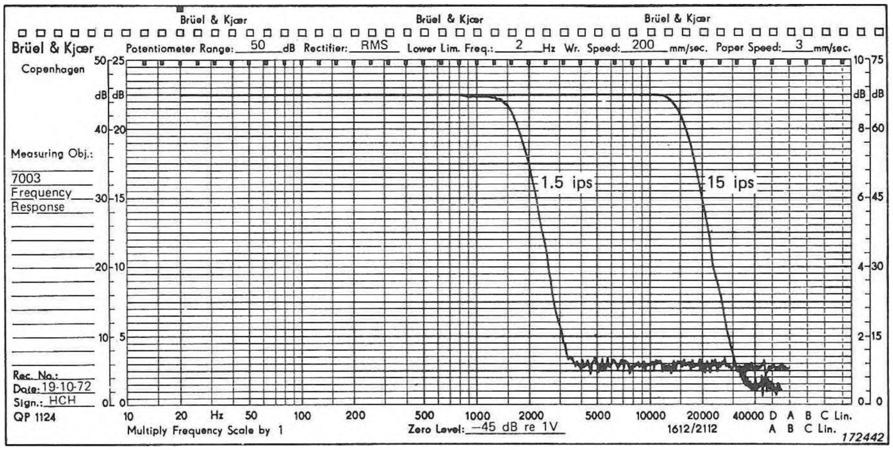


Typical cumulative inherent noise and flutter characteristics

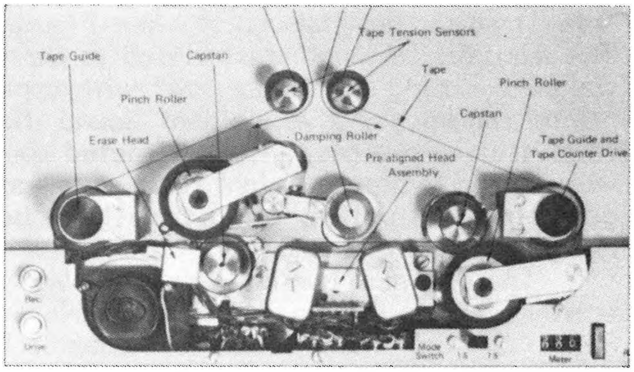


Typical frequency response curves of a measurement channel of Type 7003

The frequency response curve is incredibly flat, as the graph shows very clearly. The wide band dynamic ranges are 39 dB and 44 dB at 1.5 ips and 15 ips respectively. When used with the B & K Type 2210 sound level meter, dynamic ranges of 90 dB can be achieved.

An attractive "no charge" extra with the 7003 is a tape loop cassette which facilitates recording and play back of transients and single events.

Complete technical literature, describing all the features of the Type 7003 is available on request. Or, if you prefer, we would be most pleased to give you a practical demonstration on your own premises, completely without obligation. Simply write or phone any Bruel & Kjaer office.



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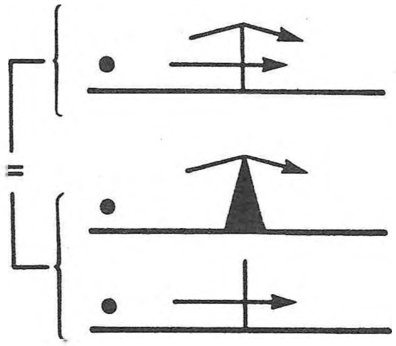


Figure 5. The two transmission paths important in noise barrier work can be treated separately.

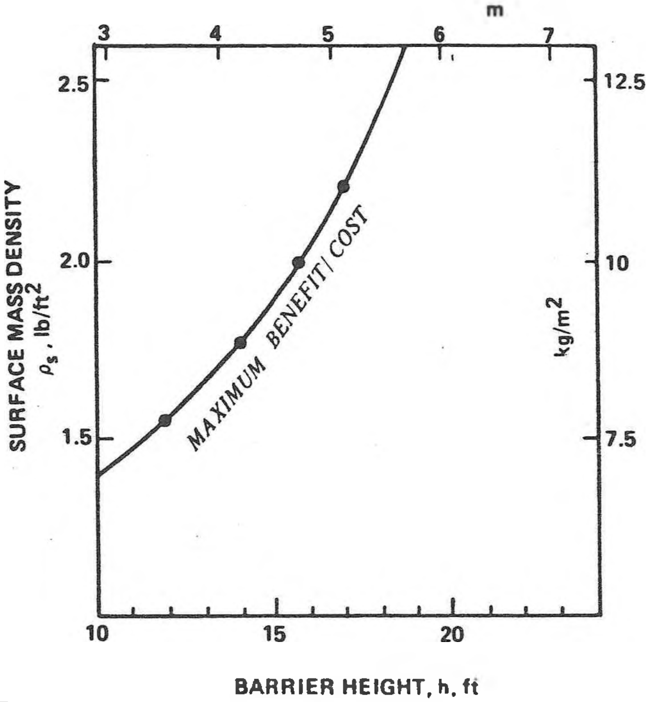


Figure 6. The optimum surface density for the panels in a steel noise barrier as a function of barrier height. (See Section 5.)

5. Barrier Weight

In the instances when barrier weight has been considered in barrier design, a panel surface weight density of 4 lb/ft^2 has become accepted as the minimum acoustical requirement.

MTC was able to revise this requirement downwards, to about 1.5 lb/ft^2 (for all materials except wood). This was achieved with a theoretical analysis, backed up by laboratory transmission loss tests (see Section 6) and full-scale barrier measurements (see Section 7).

The theoretical study considered the noise diffracted over the barrier, and the noise transmitted through it - see Figure 5. The transmitted sound was related to barrier weight by using the "mass law" with appropriate regard for the incident sound field from traffic sources. The diffracted sound was related to barrier height for a worst-case geometrical situation, using traditional barrier prediction methods.

The optimum barrier weight for various barrier heights (shown for steel barriers in Figure 6) was then found by considering actual and estimated costs for various height and weight structures. A barrier built to these principles theoretically achieves the highest overall performance at least cost. However, this is usually only true of steel barriers. (Where other materials are used, nonacoustical requirements generally dictate the weight.) MTC's steel barriers are, however, by far the least expensive, durable barriers of any we have heard of. They cost one-third to one-half what some other agencies' similar-height barriers cost. Their cost has been held roughly constant, despite inflation, for over 5 years by successively applying these and other design refinements.

The study now needs extension by considering not just panel weight, but also the structural concerns that arise when panel weight is reduced, since these can cause the barrier post spacing to be reduced. Barrier post spacing is also an important cost factor.

D. N. May, "The Optimum Weight of Highway Noise Barriers."

(1) Report 78-AC-14, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1978.

(2) Proceedings of Conference on Highway Traffic Noise Mitigation, Los Angeles, California, December 11-15, 1978, published by U. S. Department of Transportation, Washington, D. C., 1979.

(3) To be published, J. Sound Vibration, 1980.

6. Use of Damping Material

The efforts to design lightweight barriers described in Section 5 led to considering other techniques to minimize cost. One such technique was to achieve the desired structural transmission loss (TL) by paring down the weight and adding a sound damping material to restore the TL.

This was tested using a steel barrier structure and a spray-on damping material, by measuring the TL with and without the material.

A cost analysis showed savings in barrier panel material costs of between 7 and 23 percent, depending on the assumptions taken into the calculations. Further research seemed justified by these results.

A. Behar and D. N. May, "Vibration Damping Compound as a Means to Reduce Steel Noise Barrier Cost."

(1) Report 78-AC-11, Research & Development Division, Ministry of Transportation & Communications, Ontario 1978.
(2) Presented at the 50th Anniversary Meeting of the Acoustical Society of America, Cambridge, Massachusetts, June 11-15, 1979.
(3) To be published, J. Sound Vibration, 1980 (with amended title).

7. Full-Scale Barrier Noise Reduction

The noise reduction produced by a barrier is measured to confirm that the barrier performed. The need for this goes beyond precautionary monitoring of the program, and is mainly to learn how to prevent repeating mistakes in future designs. Predictions of barrier performance are by no means precise, and measurements assist in their development.

There are many pitfalls in making barrier noise measurements, since even small measurement variations may be a significant proportion of the noise difference one is trying to detect. There is no standard for barrier noise measurements, though ANSI is working on one (with MTC and NRC input).

The standard MTC measurement procedure is to measure the noise behind the barrier and, simultaneously, at a "control location." This takes place before the barrier is built and after, at identical positions and similar times of day. The control location is usually situated near the highway, but beyond the limits of the barrier, where it is used to indicate any changes in highway sound level that occur from one measurement occasion to another. The measured insertion loss of the barrier is then "normalized" by correcting for any source strength variations that are observed.

The microphones in the area behind the barrier are typically 15 ft away from reflecting structures, and are at a number of heights up to 20 ft, the main one being 4 ft high. The position of each is noted very precisely, and photographed, to ensure that "before" and "after" measurements are made in the same place. They are connected to digital sound level monitors which report the A-weighted sound levels rounded to the nearest decibel. The many statistical descriptors of relevance to traffic noise are recorded, with most emphasis being placed on L_{eq}. Each measurement period is 30 minutes, and it is the practice to measure at several points for this period of time rather than at just a few points for longer. Therefore the results are usually averaged over a number of points (e.g., "first row homes," "second row homes") to characterize the performance of the barrier.

Since ground cover and weather affect barrier performance, these are noted for future reference. A miniature weather station provides the latter.

An example of the microphone locations for a barrier measurement are given in Figure 7. In this instance, a concentration of measurement positions occurred immediately behind a 500 ft barrier test section that was variously altered so as to be (a) absorptive, (b) reflective, and (c) T-profiled. These particular measurements confirmed some of the scale-model results described in Section 3.

Some examples of relevant publications are given below. The first is of interest because it deals with the special test section described above; the second validated the use of lightweight barrier structures (see Section 5); and the third contains measurements showing that noise amplification can indeed occur on the opposite, i.e., unprotected, side of the highway, though it amounts to only about 1 dB.

D. N. May and M. M. Osman, "The Performance of Sound Absorptive, Reflective, and T-Profile Noise Barriers in Toronto."

(1) Report 79-AC-07, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1979.
(2) To be published, J. Sound Vibration, 1980 (with amended title).

D. N. May, "Noise Barrier Attenuation - Highway 401 South Side, Dixon Rd. to Kipling Ave., Toronto," Report 77-AC-09, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1977.

D. N. May, "Noise Barrier Attenuation - Highway 417 North Side, Melrose Ave. to Loretta Ave., Ottawa," Report 78-AC-13, Research & Development Division, Ministry of Transportation and Communications, Ontario, 1978.

8. Perceived Benefit from Psychoacoustic Studies

For planning purposes in barrier site selection, and also for design purposes, highway agencies need a model for barrier "benefit." Benefit in this usage must consider not just noise reduction, but also the sound level from the highway before a barrier is built. This enables a planner to decide, for example, whether a 75 dB(A) site should receive a barrier giving 8 dB noise reduction, before a 70 dB(A) site at which the same barrier would give 11 dB noise reduction.

At present such decisions are made either arbitrarily or by an empirical benefit model such as Ontario uses (see Section I). To try to establish a benefit model on a scientific basis, a laboratory experiment was performed in which 82 subjects judged the benefit of a noise barrier by listening to 32 tape recordings of before-barrier and after-barrier traffic noise. The resulting 2624 perceived benefit judgments were related by regression analysis to the barrier attenuation, the before-barrier traffic sound level, and a music background level, all of which had been varied over the 32 tapes. Prediction equations were developed for barrier benefit in terms of these sound levels.

The result of this analysis is shown in Figure 8, which allows barrier benefit, on a scale of 0-10, to be determined once the barrier noise reduction (attenuation) and before-barrier sound level are known.

An unexpected finding was that barrier benefit was highest when before-barrier sound levels were lowest; it appeared that people judge barrier benefit in terms of barrier attenuation first, and the quality of their auditory environment after a barrier is installed second, preferring a barrier that solves their noise problem to an equally-attenuating barrier that does not.

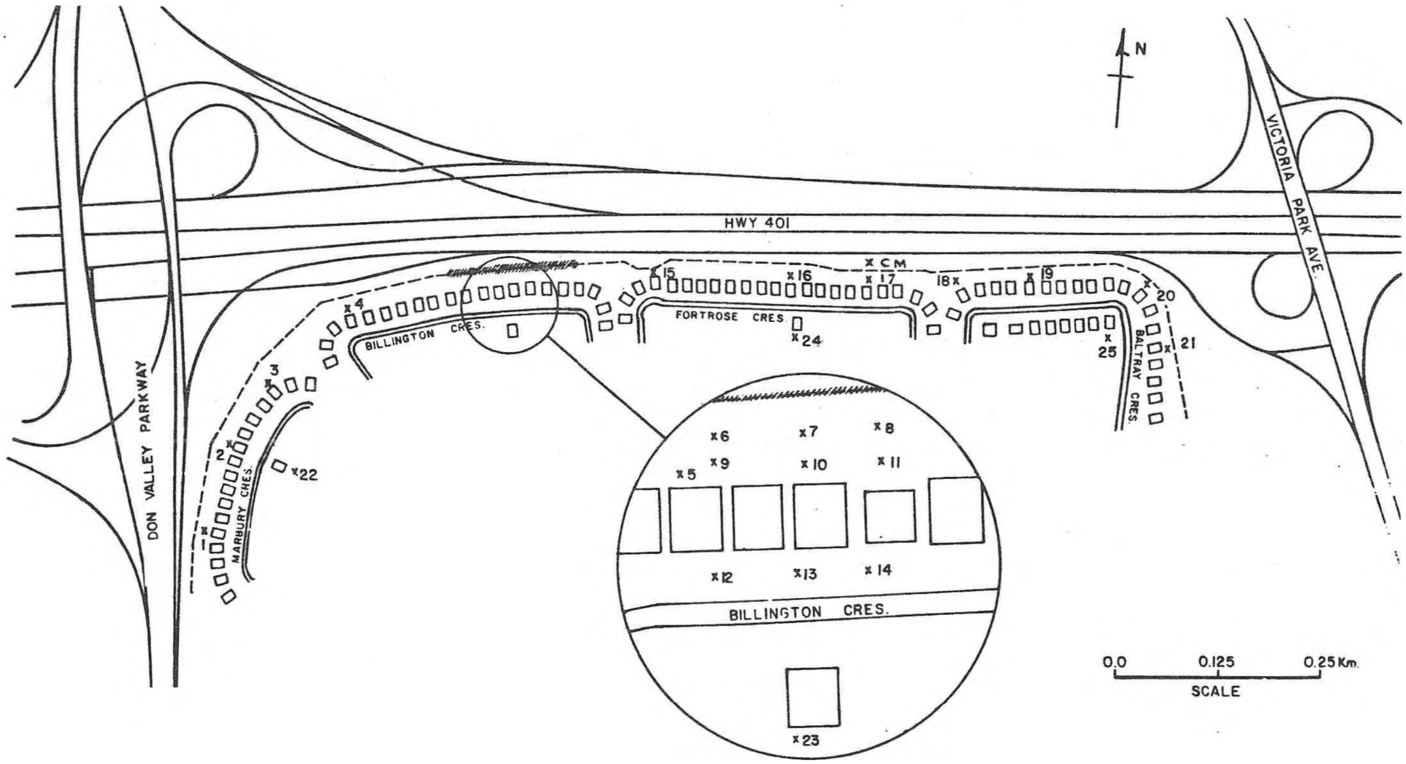
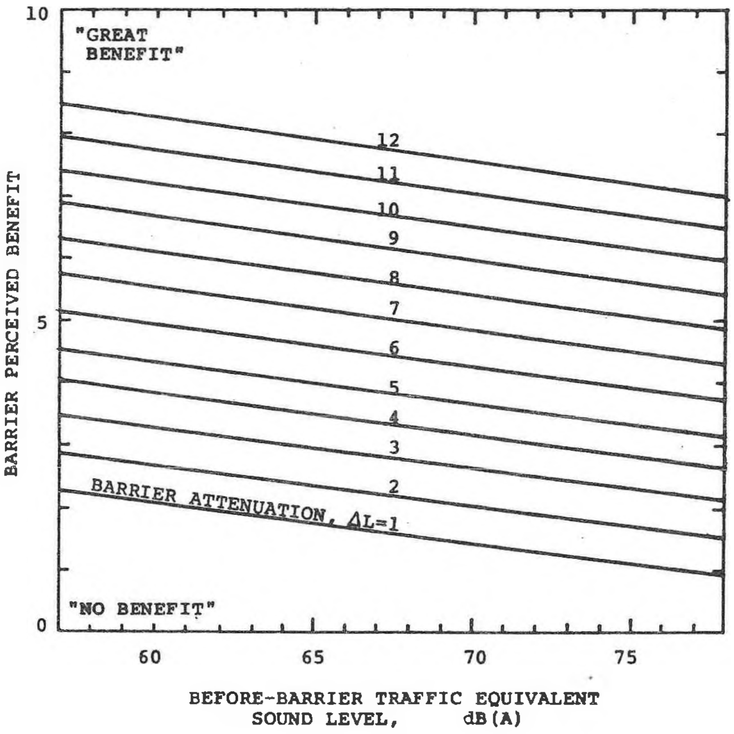


Figure 7. The measurement points for a noise barrier survey in Toronto. The barrier is shown by the dashed line. A special test section is shown hatched. The measurement points are shown by an (x) and either a number or CM (for control measurement). This particular control measurement was 20 ft high to avoid the influence of the barrier.

Figure 8. A psychoacoustical study into barrier perceived benefit produced this result in terms of barrier noise reduction and before-barrier sound level. (See Section 8.)



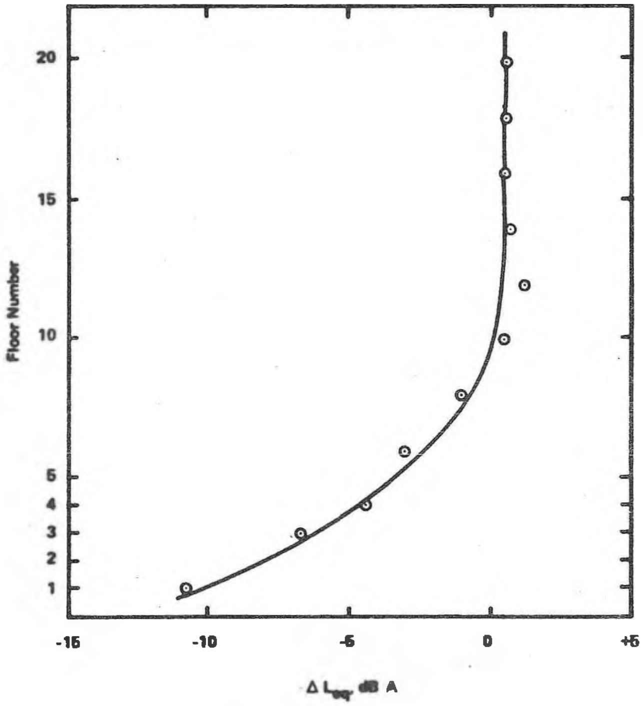
The implications of a barrier benefit model which predicts decreasing benefit with increasing before-barrier sound level must be assessed by user-agencies for themselves. Such a model suggests that the sites most severely impacted by traffic noise may be the ones that should receive them last (unless the attenuation of the barriers is sufficient to solve rather than just alleviate the noise problem). However, it may be more tenable as public policy to mitigate the most severe problems rather than solve the less severe ones. In this case the value of this benefit model is limited to pointing out the real feelings the public apparently have when a noise barrier is erected: their concern for the high level of residual sound level after the barrier is constructed may be voiced by renewed complaints at a later date.

D. N. May and M. M. Osman, "Highway Noise Barrier Perceived Benefit."

(1) Report 79-AC-05, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1979.

(2) To be published, J. Sound Vibration, 1980.

Figure 9. How sound level increased with height in a Toronto high-rise, 260 ft from a 15-lane freeway. L_{eq} is here the equivalent sound level measured 8 ft out from the building on the floor shown minus the simultaneously measured equivalent sound level 50 ft from the highway edge-of-pavement at a height of 4 ft above the ground. (This difference removes the effect of source strength variations such as arise from traffic flow irregularity.) Floors are spaced 9 ft apart. Floor 1 is at ground level. See Section 11.1.



9. Perceived Benefit from Social Surveys

Social surveys provide the final test of barrier success or failure. Those MTC undertook or commissioned all confirmed that residents were well-satisfied with their barrier.

The first survey cited below showed that most of the benefit accrued in the first row of homes. This survey also provided revealing indications of nonacoustical benefits from barriers, e.g., in reducing such things as dust and dirt, headlamp glare, salt spray, and trespassing by stranded motorists.

The second survey cited below tended to confirm the psychoacoustical result in Section 8 that residents valued a noise barrier most when before-barrier traffic sound levels were high rather than very high.

Further details of these and other interesting findings may be obtained from the survey reports:

C. Andrew and K. Sharrott, "Privacy Fence: A Survey of Public Reaction to the Privacy Fence Located Along Highway 401 within Metro Toronto Between Victoria Park and Warden Avenues," Research & Development Division, Ministry of Transportation & Communications, Ontario, 1976.

F. Schliewinsky and M. J. Adams, "Analysis of Noise Barrier Impact on Dissatisfaction with Freeway Annoyances," Research & Development Division, Ministry of Transportation & Communications, Ontario, 1979.

10. Education and Public Relations

Two useful publications in a noise barrier construction program are (a) an explanation of design principles, and (b) an audiovisual program.

An easily followed report showing how barriers work, the importance of adequate length, how to calculate noise reduction in simple situations, how "leaks" degrade performance, etc., was found invaluable. It was issued to regional engineers within the agency, and to many members of the public who wanted to do-it-themselves when they saw MTC barriers being constructed elsewhere.

An audiovisual program was produced for regional engineer use at public "drop-in" centers. Its noise effects cautioned the public not to expect too much from barriers, and its visuals gave them a good idea of what barriers look like.

D. N. May and J. J. Hajek, "Design Principles for Highway Noise Barriers," Research & Development Division, Ministry of Transportation & Communications, Ontario, 1975.

A. Behar and D. N. May, "Highway Noise Barriers - an Audiovisual Program," Reports 78-AC-10A (Users' Guide) and 78-AC-10B (Slides and Tape), Research & Development Division, Ministry of Transportation & Communications, Ontario, 1978.

11. Associated Highway Noise Research

Given in brief here is a summary of MTC highway noise research that was closely associated with the noise barrier program.

11.1 High-Rise Balconies

High-rises are not protectable by noise barriers. Moreover our measurements showed a noise increase with height due to the absence of the ground attenuation that protects low level structures - see Figure 9. To provide high-rise occupants with a way to reduce noise in this important recreational area, the use of sound absorptive treatment was tested on balcony surfaces - with satisfyingly substantial results; see Figure 10.

D. N. May, "Freeway Noise and High-Rise Balconies."

(1) Report 77-AC-2, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1977.

(2) J. Acoust. Soc. Am. 65(3), 699-704, 1979.

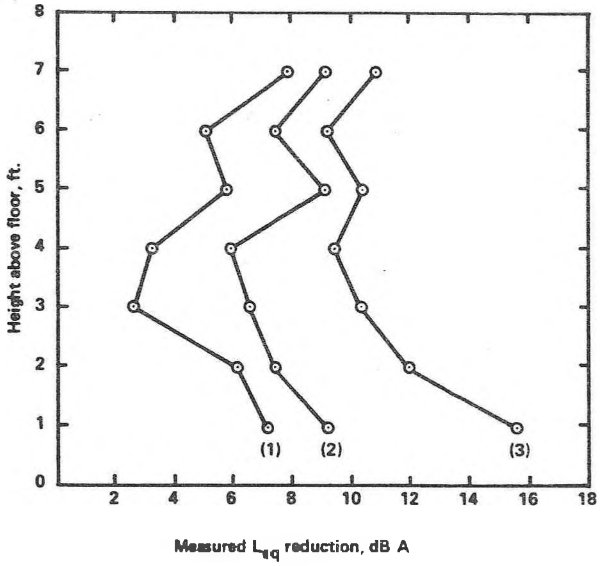


Figure 10. The substantial noise reduction produced on a 17th floor balcony by adding sound absorptive linings to (1) ceiling only, (2) ceiling and back wall, and (3) all surfaces. See Section 11.1.

11.2 Sound Level Prediction

MTC's highway noise prediction models have been highly regarded at Transportation Research Board conferences, due partly to the substantial data base of careful measurements from which they were drawn.

J. J. Hajek, "Ontario Highway Noise Prediction Method," Report RR 197, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1975.

J. J. Hajek, "An L_{eq} Traffic Noise Prediction Method."

(1) Report 78-AC-04, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1978 (first printing, 1976).

(2) Presented at the Annual Meeting of the Transportation Research Board, Washington, D. C., January 1977.

11.3 Psychoacoustical Tests of Noise Descriptors

Noise descriptors like L_{eq} and L_{10} have sometimes been criticized for a supposed inability to adequately describe traffic noise with unusual time-varying properties. A psychoacoustical study was therefore performed using a wide range of sound level standard deviations for the tape-recorded noises presented to subjects. Intrusive noises like gear changes and clearly distinguishable individual truck pass-bys were featured.

The results showed that L_{eq} was a better descriptor than other descriptors, including those which considered the sound level standard deviation. It could, however, be slightly improved by adding a term containing the number of truck gear changes. However, this addition did not seem warranted for freeway noise situations.

C. Andrew and D. N. May, "A Laboratory Study of Annoyance Due to Traffic Noise and the Choice of Noise Descriptors."

(1) Report 77-AC-1, Research & Development Division, Ministry of Transportation & Communications, Ontario, 1977.

(2) Presented at the 94th Meeting of the Acoustical Society of America, Miami, Florida, December 1977.

11.4 Pavement-Tire Noise Reduction

Pavement-tire noise reduction in association with noise barriers adds up to considerable noise alleviation potential, all within the ability of the government to provide.

MTC's research in pavement/tire noise has:

o Identified a quiet type of transverse grooving for use in restoring the skid-resistance of worn concrete pavements, and a very quiet open-graded, carpet seal mix asphalt pavement

o Developed a near-tire measurement technique

o Highlighted the relative influence of tire type and pavement type in influencing sound levels

o Developed a roadside measurement technique using a two-way analysis of variance to indicate how pavement noise level differences reduce with increasing distance from the highway.

Relevant references are:

J. J. Hajek, "Influence of Pavement Surface Textures on Highway Noise."

(1) Research & Development Division, Ministry of Transportation & Communications, Ontario, 1975.

(2) Presented at the Annual Meeting of the Canadian Acoustical Association, Toronto, October 1975.

D. N. May and M. M. Osman, "Noise from Retextured & New Concrete & Asphalt Road Surfaces."

(1) Research & Development Division, Ministry of Transportation & Communications, Ontario, 1978.

(2) Proceedings of Inter-Noise '78, San Francisco, California, May 8-10, 1978.

M. M. Osman and D. N. May, "Relative Influence of Pavement Texture and Tire Type on Pavement/Tire Noise."

(1) Report 79-AC-08, Research & Development Division, Ministry of Transportation & Communications, Ontario 1979.

(2) Proceedings of the International Tire Noise Conference, Stockholm, Sweden, August 28-30, 1979.

(3) Presented at the Society of Automotive Engineers Congress and Exposition, Detroit, February 25-29, 1980, Paper 800282 in SP 456, available from SAE, Warrendale, Pennsylvania.

Acknowledgments

I am grateful to the many colleagues at MTC who contributed to this work, in particular Chris Andrew, Alberto Behar, Jim Desormeaux, Gary Giles, Jerry Hajek, Michael Hunter, Graham Jones, Dr. Moustafa Osman, and those who sponsored it and supported us, Ian Campbell and Peter Smith. Mrs. Rosemary Garsh of Wyle Laboratories kindly assisted with her typing.

NONPATHOLOGICAL CONSIDERATIONS IN THE DETERMINATION OF BRAINSTEM ELECTRIC RESPONSE ACTIVITY

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Abstract

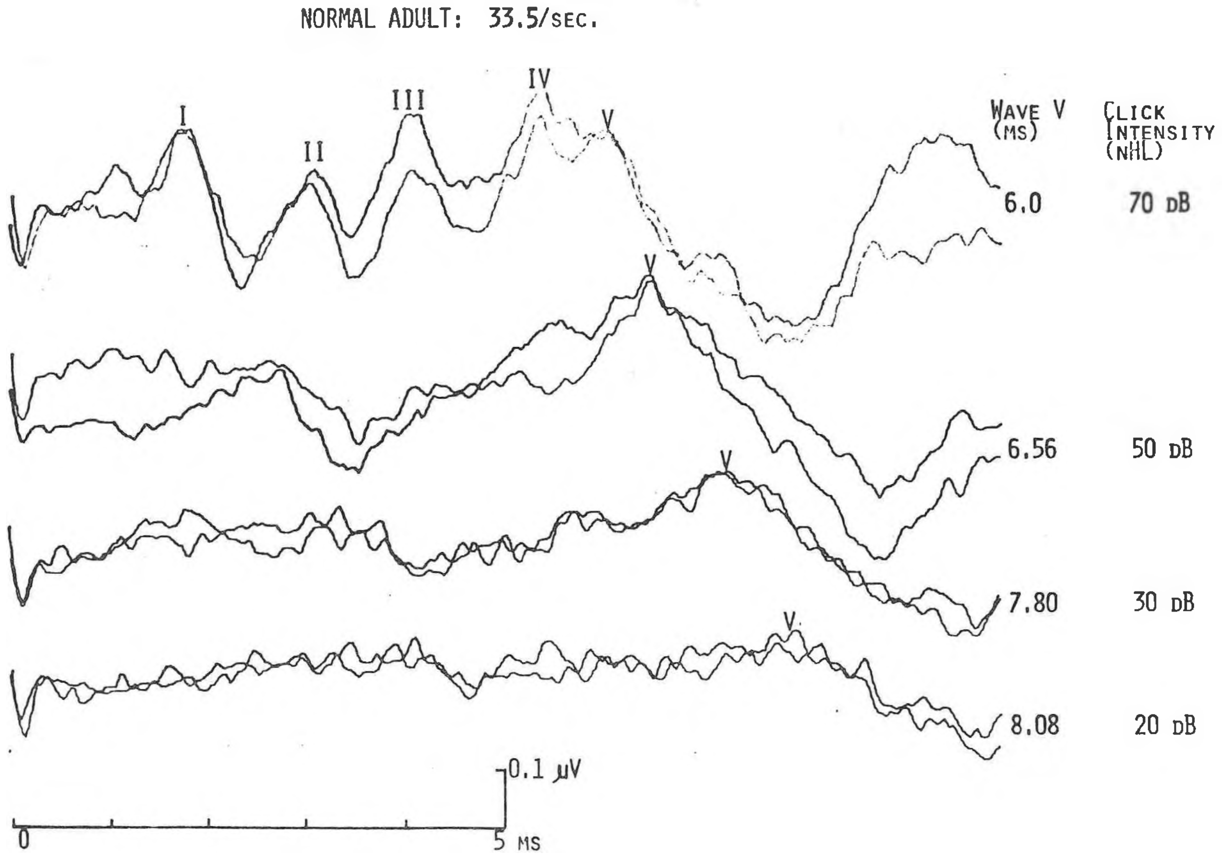
The introduction of brainstem auditory evoked potentials has provided a relatively new technique for monitoring neural activity from the auditory nerve and brainstem nuclei. It is the purpose of this paper to present the effects of stimulus presentation rate and sex on brainstem response activity. Ten normal hearing adult subjects (five male and five female) received click stimuli presented at intensity levels of 70, 50, 30, and 20 normal hearing level (nHL) at presentation rates of 10.5, 33.5, and 80.5 per second. Significant Wave V latency differences were found between male and female subjects as well as between presentation rates. Results suggest the establishment of male, female normative latency data at known presentation rates prior to the accurate assessment of auditory sensitivity or neurological brainstem disorders.

Brainstem auditory evoked potentials are measurements of electrical activity generated from the auditory pathway within the first 10-12 ms post stimulus onset. This technique, which was first reported by Jewett (1969, 1970) and his colleagues (Jewett, Romano, and Williston, 1970; Jewett and Williston, 1971) involves the use of a signal averager and focuses on the extrication of brainstem electrical potentials from random EEG activity. These brainstem potentials consist of seven measurable wave forms (Jewett and Williston, 1971), each separated in latency by approximately one millisecond and each representing successive activity within the auditory nerve and brainstem nuclei (Davis, 1976; Picton and Smith, 1978).

Research and clinical investigation in brainstem electric response (BER) activity to auditory stimuli has centered on two principal areas: 1) those concerned with neurological function and disorders and 2) those involving the auditory assessment of the peripheral hearing mechanisms (Don, et al., 1979).

The criteria used for BER interpretation is based primarily on the latency of individual wave peaks and their interpeak latencies. Due to its consistency and stability, the fifth wave has been considered prominent in the interpretation of auditory threshold sensitivity. Figure 1 illustrates an auditory electric response recorded from a normal hearing adult to a click stimulus. Four intensity levels and their respective Wave V latencies are given. Unfortunately, Wave V latency-intensity function may be affected by numerous extrinsic and intrinsic parameters (Weber and Fujikawa, 1977; Picton, et al., 1977). Two of these parameters include stimulus presentation rate and sex. Consequently, in order to establish normative data that is comparable between subjects and across clinics, and thereby the criteria for abnormality, variables must be systematically eliminated. Therefore, it is the purpose of this study to report the effects of stimulus presentation rate and sex on the BER Wave V latency-intensity function.

Figure 1. Typical brainstem electric responses recorded from a normal hearing subject to monaural click (33.3/sec) stimulus at various intensities. Note Wave V latencies increase as stimulus intensity decreases. Each traces sums 2000 responses with superimposed replicated traces obtained during the same session.



METHOD

SUBJECTS

Ten normal hearing subjects, five males and five females, were used in this experiment. Each subject had hearing threshold sensitivity of 10 dB (re: ANSI, 1969) or better at frequencies 500, 1000, 2000, 4000, and 6000 Hz. Subjects were auditorily tested immediately prior to BER using a modified method of limits.

STIMULUS

The stimuli used to elicit BER's were transient acoustic clicks. The output of each click was generated by passing square wave pulses, 80 microseconds in duration, each attenuated and amplified by a Nic 1007A Noise Masking Module and delivered to TDH 39 earphones with MX/AR 41 cushions. An alternate pulse polarity was used to reduce stimulus artifact during response averaging. The spectrum earphone output was measured in a 6 cm^3 coupler with a condensor microphone (Bruel and Kjaer 4144) housed in an artificial ear (B&K 4152) and connected to a precision sound level meter (B&K 2209). Two major peaks of energy concentration were measured at 2500 and 6300 Hz which reflect neural activity primarily from the basal portion (high frequency region) of the cochlea only.

INTENSITY

Four intensity levels of 70, 50, 30, and 20 dB normal hearing level (nHL) were chosen and randomly presented to each ear of the 10 subjects in the present study. These intensities were sufficient to permit observation of the latency shift of the Wave V component as a function of intensity change. Additionally, three presentation rates of 10.5, 33.5, and 80.5/second were counterbalanced.

TEMPORAL CONSIDERATION

An important consideration in the determination of behavioral thresholds are the temporal intergration characteristics, both stimulus duration and interstimulus latency. In order to equate threshold levels at each presentation rate, behavioral threshold levels were determined using click stimuli identical to that used for BER. To this point, behavioral thresholds were measured using a modified method of limits for each subject at each presentation rate accounting for the change in sound energy due to temporal intergration differences.

PROCEDURES

Two gold Grass clip electrodes were attached to each earlobe (A_1, A_2). One earlobe electrode was used as reference and placed ipsilateral to the stimulated ear; the contralateral clip electrode was used as ground for the remainder of the testing procedure. A silver-chloride cup electrode was attached to the vertex (Cz) as the active electrode for each of the subjects tested. Each subject rested on a reclining chair in a double-walled electrically shielded booth. Electrode resistance was measured and maintained at a level less than 3 K ohms throughout the testing procedure.

The BER's were amplified by a physiological amplifier (Nic HGA-100) with a gain of 10^4, routed through a band pass filter set at 150-3000 Hz and fed to a clinical averager (Nicolet CA-1000). A time base of 10 ms was employed and 2000 stimulus repetitions were used to obtain each BER tracing. All BER's were replicated and plotted on a Hewlett-Packard 7010 X-Y recorder for permanent storage.

RESULTS/DISCUSSION

The means and standard deviations for Wave V latencies at intensity levels of 70, 50, 30, and 20 dB nHL at three presentation rates, 10.5, 33.5, and 80.5 per second may be seen in Table 1. Three observations will be discussed from this Table. First, and consistent with previous BER research, the Wave V latency function systematically increases as stimulus intensity decreases. This consequence is due primarily to a reduction in synchronous neural firing associated with stimulus attenuation and, therefore, an increase latency in synaptic transmission; second, a Wave V latency difference is seen between male and female subjects; finally, a relationship appears to exist between presentation rate and Wave V latencies, that is, as click stimulus rate increases, Wave V latencies also increase.

In order to test each measure, a three-way analysis of variance with repeated observations for Factor B, presentation rate, and Factor C, intensity level, was conducted. Significant Wave V overall mean latency differences were computed between male/female subjects ($F=9.08$; $df=18.1$; $p < 0.01$), intensity levels ($F=308.42$; $df=54.3$; $p < 0.01$), and presentation rates ($F=18.70$; $df=36.2$; $p < 0.01$). Although the analysis of variance produced significant interactions, it could not be concluded that significant differences occurred between latencies for individual presentation rates. Subsequent *t* scores for the three presentation rates were computed. Although temporal integration characteristics were

TABLE 1. The means and standard deviations for BER Wave V latency-intensity function. For males and females at presentation rates of 80.5, 33.5, and 10.5/second. Click stimulus presented monaurally.

WAVE V LATENCY

FEMALE

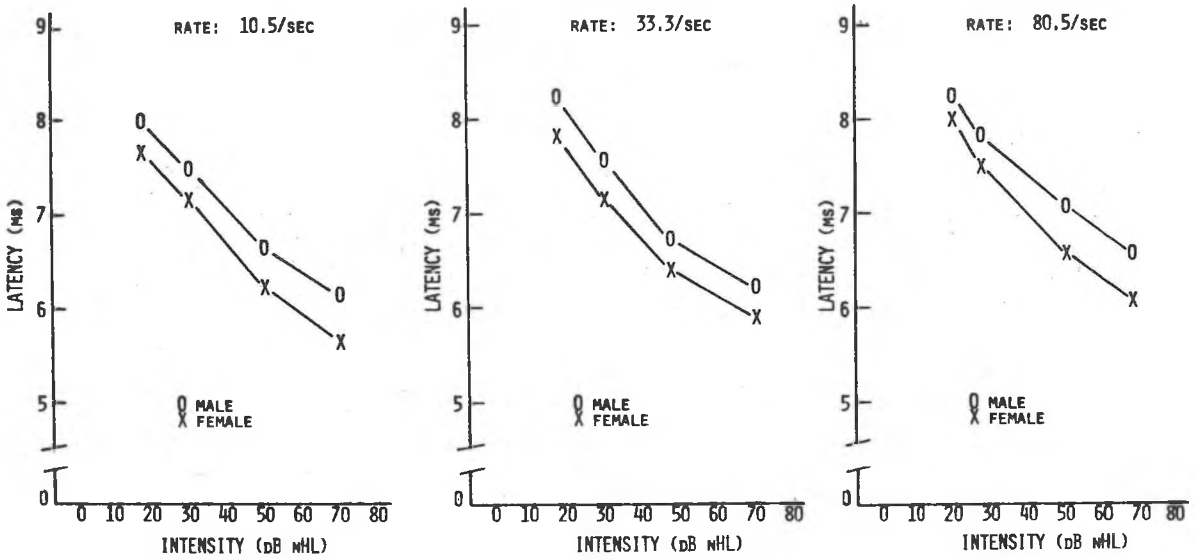
	Rate: 80.5				Rate: 33.5				Rate: 10.5			
Intensity	70	50	30	20	70	50	30	20	70	50	30	20
$\bar{X}$	5.95	6.68	7.46	8.0	5.91	6.15	7.12	7.77	5.66	6.20	7.14	7.72
S.D.	.297	.196	.271	.433	.243	.366	.311	.435	.206	.263	.366	.524

WAVE V LATENCY

MALE

	Rate: 80.5				Rate: 33.5				Rate: 10.5			
Intensity	70	50	30	20	70	50	30	20	70	50	30	20
$\bar{X}$	6.55	7.10	7.72	8.29	6.20	6.71	7.56	8.29	6.12	6.52	7.44	7.99
S.D.	.414	.346	.229	.326	.262	.283	.374	.492	.550	.401	.449	.377

Figure 2. Mean Wave V latency-intensity function for brainstem electric responses at presentation rates of 10.5/sec., 33.3/sec., and 80.5/sec. for 10 male (0) and 10 female (X) ears.



compensated for in respect to behavioral thresholds, significant Wave V mean latency differences occurred for each of the three presentation rates when compared to each other: 80.5/33.5 (t=4.35, df=19, $p < 0.001$); 80.5/10.5 (t=4.125, df=19, $p < 0.001$); 33.5/10.5 (t=3.75, df=19, $p < 0.01$). These differences in Wave V latency are most likely due to rapid repetition rate changes that occurred within the temporal integration period. While Wave V maintains its stability and measurability, increased presentation rates decrease BER resolution and may render BER uninterpretable, particularly Waves I through Wave IV.

A graphic illustration comparing the significant Wave V latency differences between male and female subjects at each of the three presentation rates may be seen in Figure 2. One factor responsible for the latency variance between males and females may be attributed to the anatomical differences associated with the distance between common synaptic junctions of the afferent auditory pathway (Stockard, et al., 1978). In particular, the area between the innervation of the acoustic nerve in the cochlea and the inferior colliculi in the midbrain. Evidence has shown consistently shorter interpeak latencies in females between these two descriptive anatomical references, attributing in part, to latency differences described in this study.

In conclusion, the results of our presentation should accurately reflect the importances of eliminating potential variability in the measurement of BER's. Sex, intensity, and presentation rate all play a significant role in the interpretation of Wave V latency values. Consequently, before establishing the limits of normalcy and thereby subsequent pathological diagnosis, non-pathological variables such as those mentioned in the present study must be well defined.

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