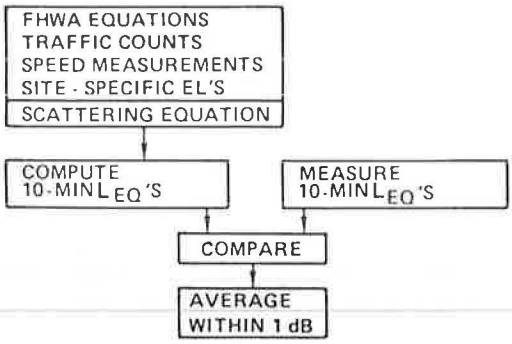


FIGURE 14 Predicted San Antonio amplification compared with Austin measurements.

to the side due to overhead reflections, and it should be less than that measured in Austin, except when both of the following occur: (a) the receptor is within 50 to 60 ft of the edge of the elevated structure, and (b) the upper roadway curves away from the receptor. When the upper roadway curves away from the receptor, its tilted undersurface tends to aim energy toward the receptor, thereby increasing the noise. The San Antonio values of 2 and 7 dB on the graph occurred at such a roadway curve, on opposite sides of the roadway.

The particular 10-lane elevated section chosen for study in San Antonio is unique. It occurs where the frontage road runs underneath the upper roadway. For most of the 10-lane elevated section there is no roadway underneath to be amplified. For this calculated cross section, where the frontage road is underneath, the upper roadway increases frontage roadway noise to the side by approximately 3 to 4 dB.

REFERENCE

1. Highway Traffic Noise Prediction Model. Report FHWA-RD-77-108. FHWA, U.S. Department of Transportation, Dec. 1978.

Publication of this paper sponsored by Committee on Transportation-Related Noise and Vibration.

Evaluation of T-Profile Highway Noise Barriers

J. J. HAJEK and C. T. BLANEY

ABSTRACT

An acoustical performance evaluation of unique 5-m-high sound-absorbing parallel highway noise barriers, with a horizontal cap to form a T-profile, is presented. The evaluation was done by using (a) direct field measurements, (b) analytical procedures based on the STAMINA 2.0 computer program and the application of geometrical acoustics, and (c) acoustical scale modeling. Noise measurements in the residential area behind the barriers indicated that the addition of a 1-m-wide horizontal cap on top of the barrier had increased its insertion loss by about 1 dB(A). Similar results were obtained by acoustical scale modeling, which also indicated that it is usually acoustically more effective to increase the barrier height rather than to build a T-top.

The objective of this paper is to present the results of an acoustical evaluation of unique parallel highway noise barriers constructed in 1983. The barriers have sound-absorptive layers on both the highway and the residential sides. A 1-m-wide sound-absorptive cap is mounted horizontally on top to create a T-profile.

The evaluation has been conducted by using direct field measurements, analytical calculations, and acoustical scale modeling. The latter two methods were used to establish their accuracy in relation to the field measurements and to evaluate various design parameters, such as the T-top shape and absorptive treatment of barrier walls, which could not be evaluated effectively in the field.

The barriers are located along both sides of the Queen Elizabeth Way (QEW), east of Cawthra Road in Mississauga, Ontario. At this location the QEW has six traffic lanes, three in each direction, and the barriers are about 36 m apart. On both sides of the QEW there are two-lane service roads. The terrain is flat, gently sloping toward the south (Lake Ontario). Figure 1 shows the general barrier setting, together with the location of T-top and conventional barriers, and the measurement locations used for evaluation.

The photographs in Figures 2 and 3 have been included to illustrate the appearance and aesthetics of T-top barriers. Although opinions in these matters can certainly differ, the addition of the horizontal cap does not appear to degrade the appearance of a conventional type barrier.

Construction of noise barriers at this site had been anticipated during highway construction in 1977. Thus 0.8- to 1.2-m-high New Jersey (NJ) type

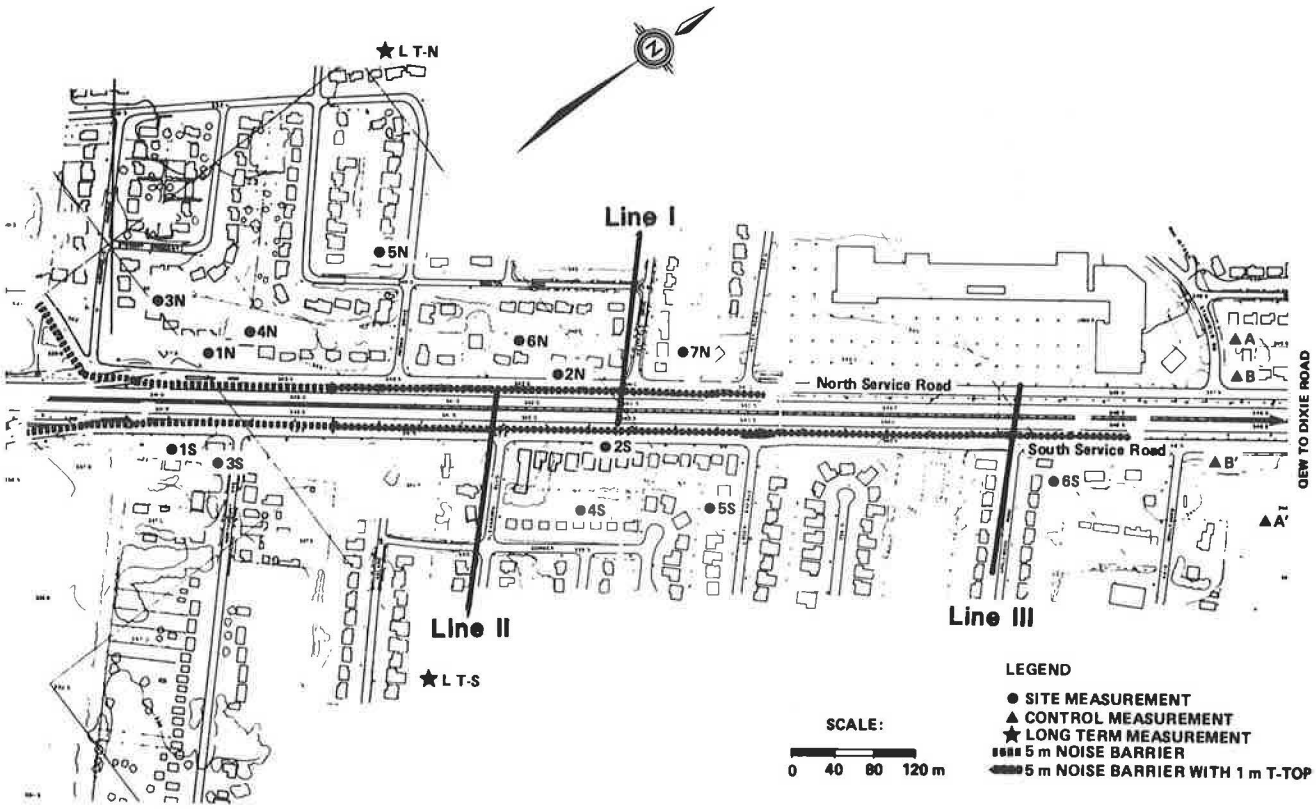


FIGURE 1 QEW, Cawthra to Dixie roads, general setting.

FIGURE 2 Site overview from the pedestrian overpass (North Service Road is on the right).

FIGURE 3 View from the residential side showing T-top and conventional barriers.

walls, which would separate the QEW from the service roads, were designed to serve also as a foundation for noise barriers (Figure 4). Because of the foundation design, the height of possible noise barriers was limited by wind load considerations to 4 m above the NJ walls (i.e., to about 5 m above the pavement elevation). This height restriction placed a limit on performance of the noise barrier (1).

The need for higher insertion loss (than that predicted for 4-m-high barriers mounted on top of NJ walls) without exceeding the total barrier height of 5 m was the main reason why T-top experimental barriers were constructed at this site. Research and development considerations, such as the effect of barrier shape and community acceptance, also contributed to the decision.

PREVIOUS EXPERIENCE

May and Osman (2) conducted a comprehensive acoustical scale-modeling study on different barrier shapes and reported a 3 dB(A) increase in the barrier insertion loss with a 1-m increase in the width of the horizontal cap. This rate compared well with the insertion loss growth rate of about 2 dB(A) per 1-m increase in the height of a conventional barrier found for the same test situation. The study also recommended an absorptive treatment of the horizontal cap on the upper surface.

Although it appears that the present application is the first actual installation of a T-top barrier, two previous full-scale experiments were found. In a report evaluating the Doublewal noise barrier (3,p.27), it was noted that there was no discernible difference in the barrier insertion loss if the barrier was fitted with a 1.5- or 2.4-m-wide T-top. (The thickness of the basic Doublewal unit was about 1.2 m.) On the other hand, it was reported that temporary addition of a 0.75-m-wide horizontal cap, 2 cm thick, to an existing 4-m-high noise barrier had increased its insertion loss by about 1 to 1.5 dB(A) (4).

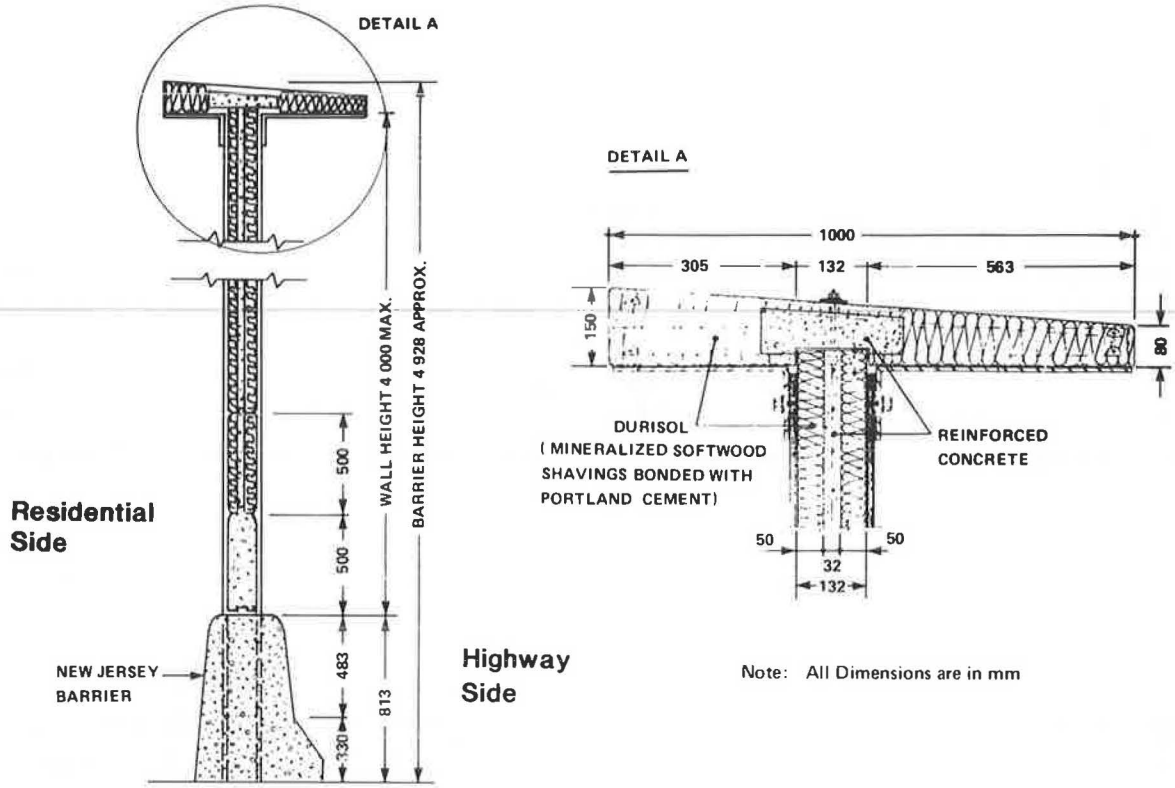


FIGURE 4 Construction details of T-profile noise barrier mounted on NJ wall.

BARRIER DESIGN AND CONSTRUCTION

The design and construction of the Cawthra Road barriers were based on a study by Hajek et al. (1), which recommended a sound-absorptive treatment on the barrier side facing the highway (freeway side) as well as on the side facing the service roads (residential side). The recommendation for the sound-absorptive treatment on the freeway sides was based on the evaluation of multiple reflections caused by parallel barriers, according to a procedure outlined elsewhere (1,5).

The recommendation for a sound-absorptive treatment on the residential side was based on sound levels emitted by traffic on service roads that cannot be attenuated by noise barriers. A 12-hr traffic classification survey, conducted in April 1981, indicated that traffic on the service road was relatively high. Depending on time, the South Service Road traffic volumes represented about 15 to 28 percent of the eastbound QEW traffic, and the North Service Road traffic volumes represented about 12 to 18 percent of the westbound QEW traffic (1). It was feared that if the barriers were sound reflecting on the residential side, they would reflect sound from the service road traffic to the community behind the barrier and amplify it by as much as 3 dB(A).

A typical barrier construction detail, showing the T-top, is shown in Figure 4. Sound-absorptive treatment consisted of a Durisol building material, which is described as a lightweight material (density of about 560 kg/m³) made of chemically mineralized and neutralized softwood shavings bounded together under pressure with portland cement. It is an open-textured material with a noise reduction coefficient (NRC) of about 0.60 for 5-cm thickness when mounted against a rigid backing. The structural support for Durisol was provided by a steel-reinforced concrete core. The complete panels are 3 m long, 0.5 m high, and 0.132 m thick. The panels are interlocking with tongue-and-groove joints, and the joints between the panels and steel posts are sealed with a rubberized compound. The first panel on top of the NJ walls was an all-concrete panel.

FIELD EVALUATION

The acoustical performance of the barriers was assessed by comparing sound levels measured before the barrier construction with the sound levels measured (a) after the erection of sound-absorptive vertical barriers and (b) after the addition of the horizontal cap. The before-and-after measurements were done on identical locations in the residential community behind the barriers and during similar times of the day.

The measured barrier insertion loss was normalized to remove the effects of source strength and other variations as described in previous studies by the Ontario Ministry of Transportation and Communications (MTC) (4,6), where sound levels were measured behind the barrier and, simultaneously, at a control measurement location unaffected by barrier construction, both before and after barrier erection. In this study the procedure was slightly modified in that two control locations, rather than one, were used to indicate any changes that may occur between the measurements. The first control measurement location was close to the highway (about 40 m from the centerline, 4 m aboveground) and was intended to account mainly for the source strength (traffic) variation. The second control location was farther from the highway (about 90 m from the centerline, 1.2 m aboveground) and was intended to account, in addition to the source strength variation, for weather-related factors (e.g., wind and temperature gradients, wind speed) and ground condi-

tions that were not fully accounted for by the control measurement placed close to the highway. Two control measurements were used on each highway side, as shown in Figure 1.

Altogether four types of acoustical field evaluations were conducted in the area behind the barriers, as described in the following sections.

Measurements at Single Location Sites

At the single location sites, shown in Figure 1, measurements were done in two measurement series: before barrier construction and after the completion of the barrier, including the T-top. The data in Table 1 summarize the measurement results as well as the predicted results described later. Overall, the barrier insertion loss was rather limited; the first row housing receivers attaining about 5 dB(A), and the more distant ones from about 2 to 4 dB(A).

Measurement Lines

The (three) measurement lines (shown in Figure 1) served as the main evaluating tool. The sound level measurements at these lines were done before barrier construction and then at several construction stages (e.g., after barrier construction to a height of 3 m, after its extension to 5 m, and after the T-top was in place). At each stage the measurements were repeated at least two times on different days and were of 20 min duration. Figures 5-7 show average measured results before the barrier construction and after construction of the 5-m barrier without the T-top. The reason why the T-top results are not shown are rather insignificant changes in levels due

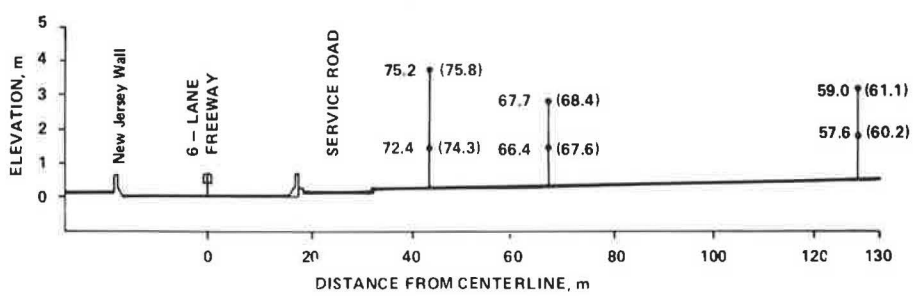
TABLE 1 Comparison of Measured and Predicted Sound Levels

Measurement Location[a]	Sound Levels Before Barrier, L_{eq} [dB(A)]		Barrier Insertion Loss, ΔL_{eq} [dB(A)]	
	Measured	Predicted	Measured[b]	Predicted[c]
Part A: Locations not Shielded by Houses				
1N	74.0	74.7	4.3	5.3
2N	75.4	75.9	5.1	5.7
1S	73.4	74.4	4.4	4.7
2S	74.3	74.5	4.7	5.3
Avg	74.3	74.9	4.6	5.3
Part B: Locations Shielded by One or More Rows of Houses				
3N	62.3	64.4	2.2	2.4
4N	64.9	66.0	3.3	4.1
5N	58.6	59.4	3.5	1.4
6N	62.0	63.7	4.3	4.4
7N	66.1	67.7	4.5	3.2
3S	64.0	66.0	4.7	4.1
4S	60.3	63.1	2.9	2.2
5S	58.6	61.0	4.0	2.7
6S	66.0	67.4	3.7	5.8
Avg	62.5	64.3	3.7	3.4
Part C: Control Measurement Locations				
A	68.2	67.1		
B	77.2	76.5		
A[1]	65.6	66.1		
B[1]	76.3	76.4		
Avg	71.8	71.5		

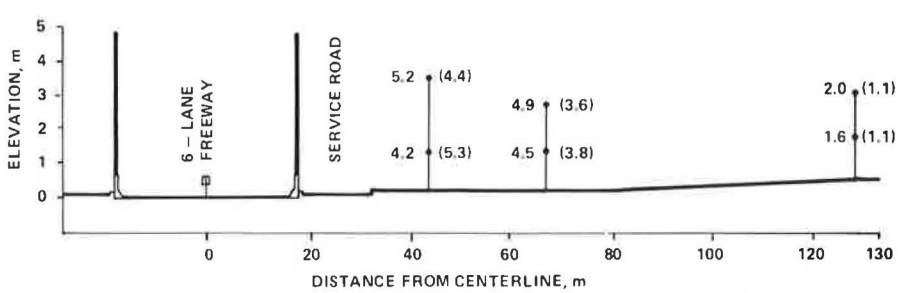
[a]Measurement locations are shown in Figure 1. All measurements were taken 1.2 m aboveground and were of 20-min duration.

[b]Measured insertion losses have been adjusted for traffic and other variations by using control measurements. The insertion loss measurements were done after the construction of the T-top.

[c]The effect of the T-top was not included in the calculations.



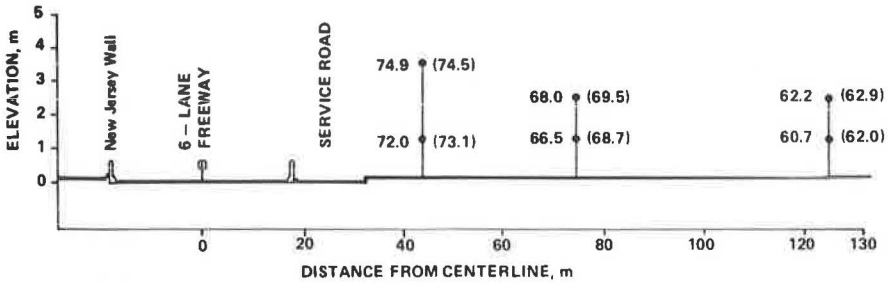
a) Average Sound Levels Measured (and Predicted) Before Barrier Construction, L_{eq}
Includes New Jersey Walls



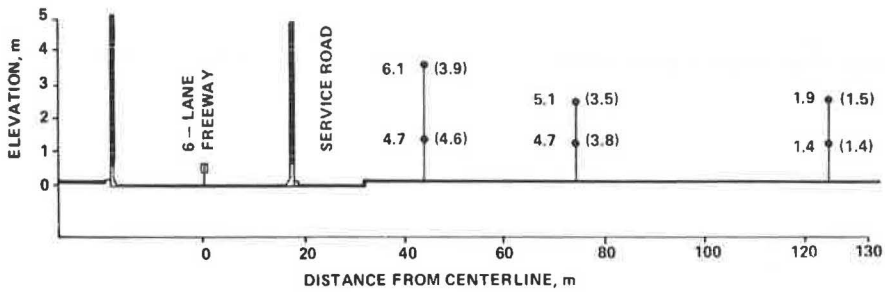
b) Average Insertion Loss Measured (and Predicted) After Barrier Construction, L_{eq}
Includes New Jersey Walls and Barriers

LEGEND
75.2 Measured Level
(75.8) Calculated Level
• Microphone Location

FIGURE 5 Comparison of measured and predicted sound levels, Line I.



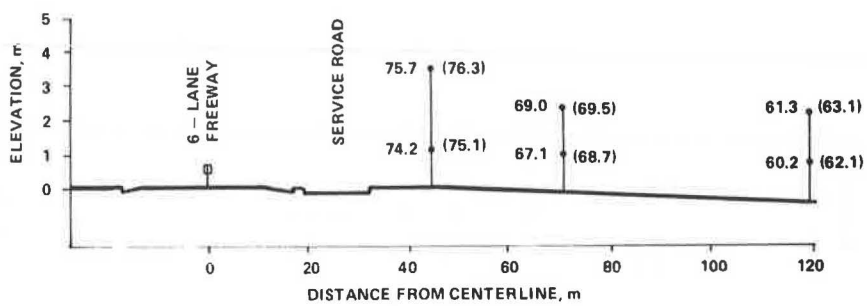
a) Average Sound Levels Measured (and Predicted) Before Barrier Construction, L_{eq}
Includes New Jersey Walls



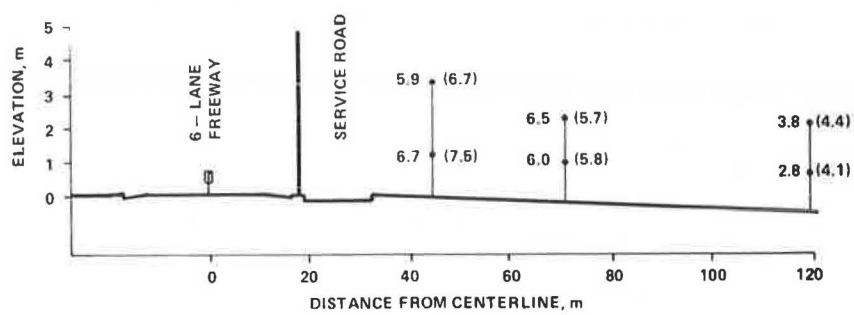
b) Average Insertion Loss Measured (and Predicted) After Barrier Construction, L_{eq}
Includes New Jersey Walls and Barriers

LEGEND
74.9 Measured Level
(74.5) Calculated Level
• Microphone Location

FIGURE 6 Comparison of measured and predicted sound levels, Line II.



a) Average Sound Levels Measured (and Predicted) Before Barrier Construction, L_{eq}



b) Average Insertion Loss Measured(and Predicted) After Barrier Construction, L_{eq}

LEGEND
75.7 Measured Level
(76.3) Calculated Level
• Microphone Location

FIGURE 7 Comparison of measured and predicted sound levels, Line III.

to the T-top. This, together with the calculated results also shown in the figures, are discussed later.

Direct Comparison of Conventional and T-Top Barriers

A direct comparison of the conventional versus T-top barriers was done at the western end of the site where these two barrier types were constructed side-by-side (Figure 1). Measurements were done by using, simultaneously, four type 1 sound level meters (7), two located behind the conventional barrier at various distances and heights aboveground, and the other two located behind the T-top barrier at the same distances and heights as their conventional barrier counterparts. Because all variables at the two measurement sites were the same (e.g., traffic, weather-related variables, height of the barrier not including the thickness of the horizontal cap, distance behind the barrier), with the exception of the T-top, the differences between the two sets of measurements were attributed to the influence of the T-top only.

Based on extensive measurements, the contribution of the T-top was rather limited and amounted to only about 1 dB(A) if the effect of service road traffic was eliminated during the measurements. The contribution was less than 1 dB(A) if the traffic on service roads was included. A similar limited influence of the T-top was measured at the measurement lines.

Long-Term Monitoring

In order to evaluate long-term changes in sound levels associated with the construction of parallel barriers, a separate measurement procedure was conducted. Also, the MTC has received a number of complaints from residents (often living several hundred meters behind highway noise barriers) that noise has actually increased after barrier construction.

Two locations, approximately 350 m from the highway centerline, were selected, one on each side of the highway (see Figure 1). At these locations five 24-hr sound level measurements were conducted before barrier construction and eight to ten 24-hr measurements were conducted after construction. The results, summarized in Figure 8, show a considerable day-to-day variation in sound levels. No statistically significant difference between the before-and-after sound levels, or between the north side and south side sound levels (Figure 8a), was obtained. The influence of weather-related variables on the measured sound levels was studied, but it was difficult to quantify because of the transient nature of these variables. The nighttime sound levels were about 6 dB(A) lower than the daytime levels (Figure 8b) both before and after barrier construction.

ANALYTICAL EVALUATION

In addition to the field measurements, the barriers were also evaluated analytically by using the STAMINA 2.0 computer program (8). To account for the effect of multiple reflections off parallel barrier walls, a number of image roadways were constructed by using principles of geometrical acoustics and were included in the program input. The procedure is explained elsewhere (9). Alternatively, the calculations can be performed more easily by using a computer program developed by Bowlby and Cohn (10).

The reasons for the analytical evaluation of the completed barriers were three-fold:

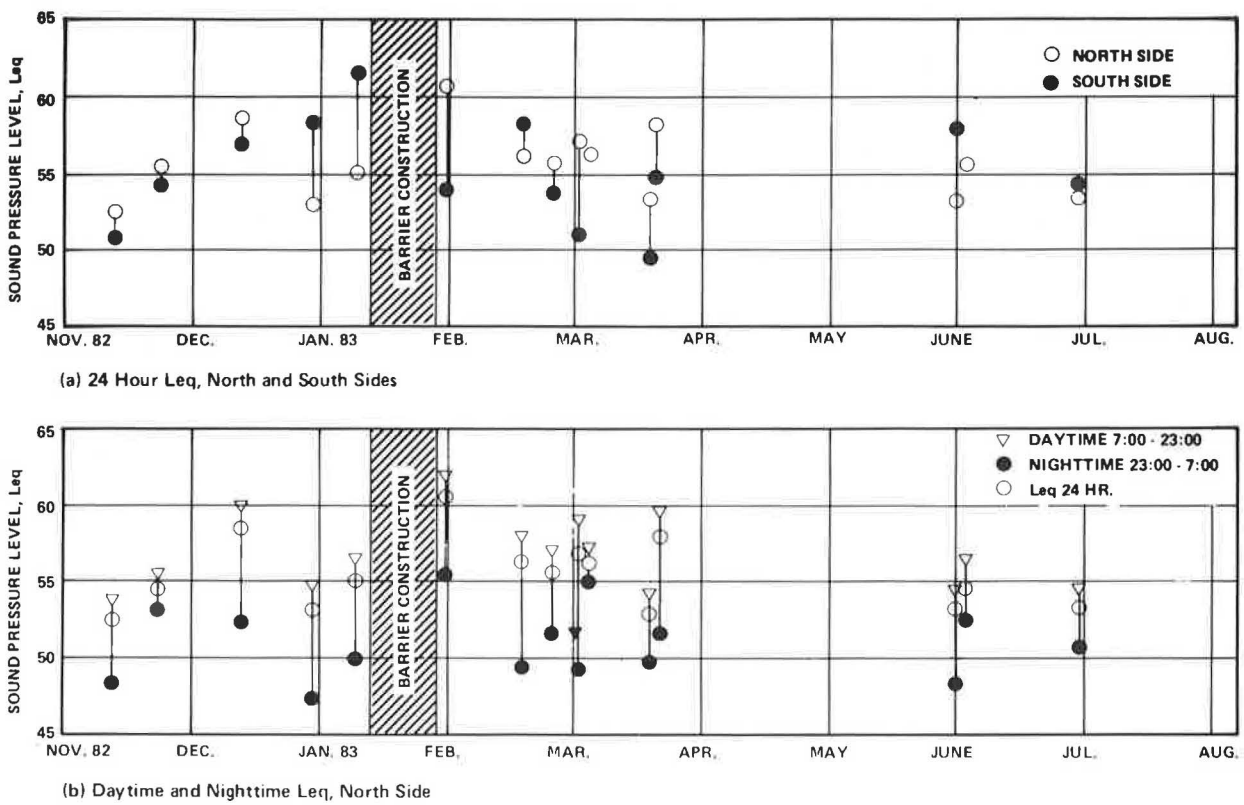


FIGURE 8 Long-term (24-hr) measurements at distant locations (approximately 350 m from centerline) before and after barrier construction.

1. To verify the accuracy of the prediction procedure and its applicability to a parallel barrier situation with barrier surfaces partly sound absorbing,
2. To quantify the effectiveness of the sound-absorptive treatment used at this site, and
3. To evaluate the effectiveness of alternative designs that may be required for different barrier sites.

The measured and predicted results are compared in Table 1 and in Figures 5-7. In general, there was satisfactory agreement between the measured and predicted sound levels and insertion losses. This reflects well on both the STAMINA 2.0 program and on the procedure used to account for the parallel barrier situation. However, sound levels at locations shielded by one or more rows of houses were consistently over-predicted by about 1 or 2 dB(A). This may be attributed to rather subjective selection of housing shielding factors or to the prediction procedure. At any rate, it appears that the overall accuracy of the predictions is adequate and that the prediction methodology can be used with confidence for alternative designs.

The predicted insertion losses for the existing and alternative barrier designs are given in Table 2 for three typical receiver types:

1. Receivers unshielded by houses (front yard receivers),
2. Receivers shielded by one row of houses (receivers in the back yards of the first housing row), and
3. Receivers shielded by two or more rows of houses.

Row 3 in Table 2 indicates that the predicted insertion loss provided by NJ walls alone ranges from 0.2 to 0.7 dB(A). It should be stressed that the measured results, reported in Table 1 and in Figures 5 and 6, indicate only the insertion losses caused by the erection of the noise barriers on top of the NJ walls. The total insertion loss, including that predicted for the NJ walls, is thus 0.2 to 0.7 dB(A) higher.

Based on the predicted data given in row 4 of Table 2, the insertion loss of the existing barriers would have been reduced by 1.1 to 2.6 dB(A) if sound-reflecting barriers (NRC = 0.05) were built instead. If the barriers were fully sound absorptive (NRC = 1.00), the insertion loss of the existing barriers (NRC = 0.60) would have been increased by 1.7 to 3.4 dB(A) (row 5, Table 2). It may be noted that the additional insertion loss from the absorptive treatment increases with the distance from the barrier. For example, the additional insertion loss for the north-side receivers is 1.7 dB(A) for unshielded receivers, and increases to 3.4 dB(A) for receivers shielded by two or three rows of houses.

The last row in Table 2 indicates that the existing absorptive treatment on the residential side had only a limited effect. The reason is that the first 1.5 m of the barrier structures are made of concrete (NJ wall plus the first barrier panel) and are sound reflecting. Based on the principles of geometrical acoustics and considering receivers close to the ground, the sound-absorptive treatment above the height of 1.5 m is beneficial only for noise emitted by heavy trucks. The absorptive treatment on the residential side should have extended as low to the ground as possible, but it did not have to reach to the top of the barrier. Because the degradation effect of multiple reflections between the barriers exceeds that of a single reflection off the residential side, and because of the different reflection geometries involved, the amount and the placement of the absorptive treatment on the two barrier sides should be optimized to achieve maximum acoustical effectiveness at the lowest cost.

SCALE-MODELING EVALUATION

In addition to the field and analytical evaluations, a congruent acoustical scale-modeling study was conducted at the MTC scale-modeling facility. The equipment and materials used were described by Osman (11,12) and have been used extensively (4,13). The use of scale modeling provides a rapid and inexpensive way to evaluate a number of alternative designs and situations (e.g., T-profile dimensions and materials, and the source, barrier, and receiver geometry) that would be impractical or impossible to evaluate in any other way. The objective of the scale-modeling study was to verify the accuracy of scale modeling and to determine optimal design parameters of T-profile barriers.

A 1:16 scale model was used for both spatial variables and the A-weighted traffic noise spectra. However, all dimensions quoted in the following paragraphs are full-scale equivalents. The sound-absorptive properties of the model materials (such as grassland, barrier surfaces, and pavements) were tested to ensure that they appropriately modeled the actual materials on the 1:16 scale. The acoustical hardware consisted of a high voltage spark as a noise source, a 0.125-in. microphone, filtering and processing instrumentation, and an oscilloscope.

TABLE 2 Insertion Loss Prediction for Different Barrier Alternatives

		Receivers Unshielded by Houses (front yard)		Receivers Shielded by One Row of Houses		Receivers Shielded by Two or Three Rows of Houses	
Row	Alternative Barrier Arrangement	North Side	South Side	North Side	South Side	North Side	South Side
1	Insertion loss of existing barriers, including insertion loss provided by NJ walls	6.1	5.7	4.0	3.5	1.4	1.6
2	Insertion loss of existing barriers, not including insertion loss provided by NJ walls	5.5	5.0	3.5	3.1	1.2	1.4
3	Insertion loss provided by NJ walls alone	0.6	0.7	0.5	0.4	0.2	0.2
4	Reduction in insertion loss of existing barriers if sound-reflecting barriers on both sides (NRC = 0.05) were built instead	1.2	1.1	1.9	1.4	2.6	1.5
5	Increase in insertion loss for existing barriers if fully sound-absorptive barriers (NRC = 1.00) were built on both sides instead	1.7	2.7	2.6	3.4	3.4	3.4
6	Reduction in insertion loss for existing barriers if the residential sides only were changed to be sound reflecting (NRC = 0.05)	0.1	0.1	0.1	0.1	0.1	0.1

Note: Results are averaged over a number of points (site measurement points and line measurements, see Figure 1). All locations were 1.2 m aboveground behind the parallel barrier corridor. Calculation assumes a conventional barrier (no T-top). NRC = noise reduction coefficient.

The source, barrier, and receiver geometry used, shown in the lower portions of Figures 9 and 10, was selected to model the Cawthra Road site. For simplicity, the majority of tests were done by using a point source only. Some of the single-point source tests were repeated by using an incoherent line source, created by moving a point source at small intervals along a line. The results indicated that although the absolute insertion loss values were smaller for the incoherent line source, the point source was sufficient to indicate the relative performance of different barrier shapes. Consequently, only the point-source results are reported here.

A number of different horizontal caps, mounted on top of 4- to 5-m-high conventional barriers, were evaluated. The T-tops differed in width (from 1 to 2 m), thickness (from 3 to 25 cm), shape (sharp-edged and rounded), their position relative to the barrier center (larger or smaller overhang toward the source), and material (reflective, NRC = 0.05; absorptive, NRC = 0.75). However, with the exception of the T-top width, these variables, within the ranges defined, had a small, hardly measurable influence on the insertion loss.

The addition of a 1-m-wide T-top to a 5-m-high barrier increased the insertion loss (e.g., 40 m behind the barrier, 1.2 m aboveground) by about 1 dB(A) (Figure 9). This is the same increase measured in the field. The addition of a 2-m-wide T-top to the identical barrier increased its insertion loss by about 2 dB(A) (Figure 10). A similar 2 dB(A) increase was obtained by increasing the barrier height by 2 m.

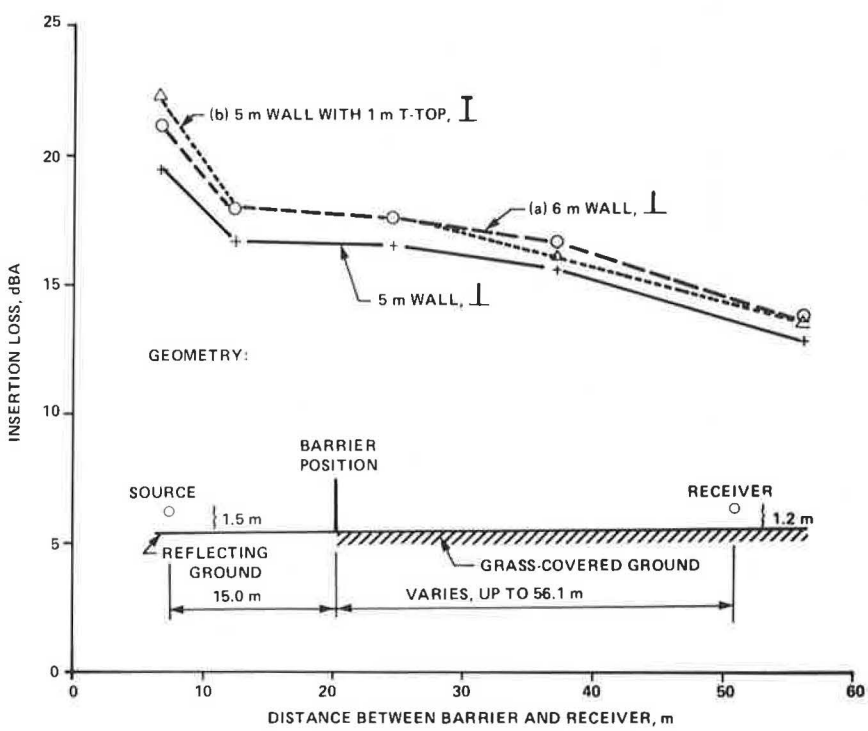
T-Top Versus Increased Barrier Height

The insertion loss of barriers with the T-top is also compared in Figures 9 and 10 with that of barriers that have increased heights equal to the T-top width (vertical cap). According to these figures, at short distances behind the barrier (10 to 20 m), the T-top provides a higher insertion loss than its vertical cap counterpart. At larger distances behind the barrier (30 to 40 m), the vertical cap provides a somewhat larger insertion loss. These results apply only for the source, barrier, and receiver geometry shown in Figures 9 and 10.

A more extensive comparison of horizontal and vertical barrier extensions, covering many receiver positions, is shown in Figure 11 by means of isodecibel lines or, in regions where isodecibel lines were difficult to define, by single measurement points. According to Figure 11a, the addition of the T-top provides the greatest insertion loss increase for receivers just behind the barrier, close to the ground. The addition to the barrier height (Figure 11b) is most effective for receivers also close behind the barrier, but higher above the ground. Figure 11c shows that the 1-m vertical addition provides higher insertion loss than the 1-m T-top for all receivers more than about 20 m behind the barrier. Only at distances less than 10 m behind the barrier is the T-top addition better than the vertical one. It appears that given a choice and the same amount of material, it is acoustically more effective to increase barrier height rather than to build a T-top.

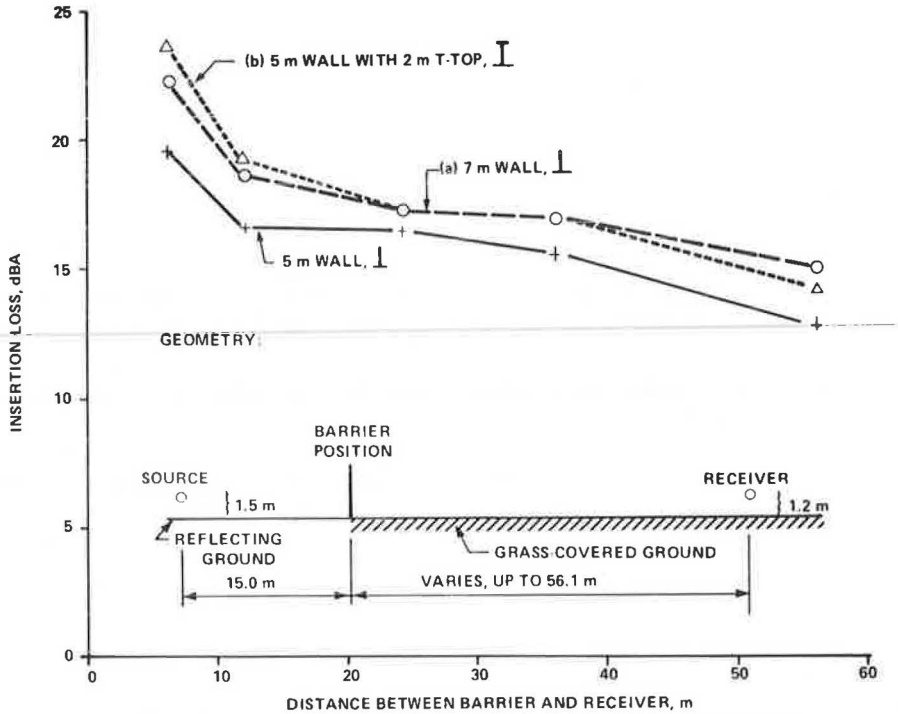
Discussion of Results

The beneficial effect of T-profile was theorized by May and Osman to be "due to the limited opportunity for pressure doubling to occur at the point that the incident wave impinges on this barrier at the end of the T" (4). Incidentally, this was the main reason why the T-top was positioned to overhang more on the freeway side (main source side) than on the residen-



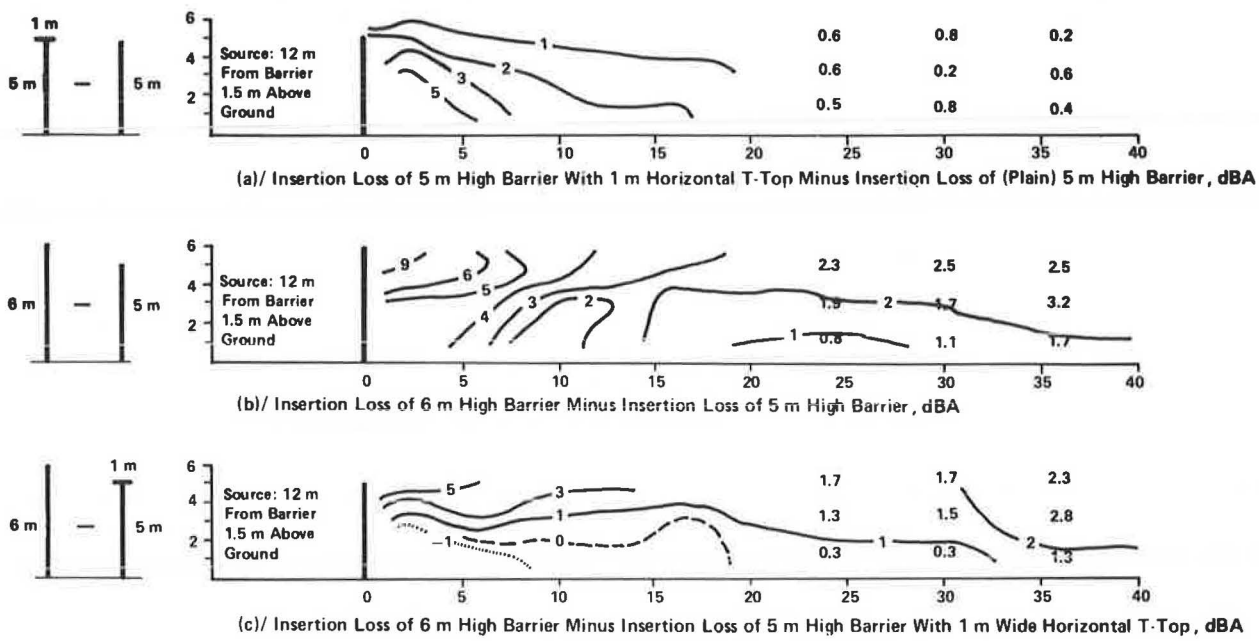
Note: The horizontal top overhang on the source side is about twice that on the receiver side. Results are obtained by acoustical scale modeling.

FIGURE 9 Change in insertion loss of 5-m-high barrier due to (a) increase in barrier height by 1 m and (b) addition of 1-m-wide horizontal T-top.



Note. The horizontal top overhang on the source side is about twice that on the receiver side. Results are obtained by acoustical scale modeling.

FIGURE 10 Change in insertion loss of 5-m-high barrier due to (a) increase in barrier height by 2 m and (b) addition of 2-m-wide horizontal T-top.



Note: The ground behind the barrier is sound absorptive (grass covered), and the ground in front of the barrier is sound reflecting (pavement).

FIGURE 11 Comparison of insertion losses (obtained by scale model measurements) for 5-m-high barrier, with and without 1-m-wide horizontal T-top and 6-m-high barrier.

tial side (Figure 4). Even though the T-top has not produced the expected results [as based on data by Mays and Osman (4)], the increase in the insertion loss due to the T-top was still somewhat larger than that predicted for the change in the path-length difference alone. This additional increase may be attributed to the pressure doubling effect previously described or to the effect of double diffraction or, perhaps, to other causes. At any rate, when the effect of the T-top is compounded with other effects of outdoor sound propagation, such as refraction and scattering in the atmosphere, it

appears that only limited acoustical benefits can be expected from sophisticated barrier shape designs similar to the T-top.

CONCLUSIONS AND RECOMMENDATIONS

1. Based on noise measurements in the residential area behind the barrier, the addition of a 1-m-wide T-top to a 5-m-high barrier has increased the barrier insertion loss by about 1 dB(A). Similar results were obtained by using acoustical scale modeling.
2. To increase barrier insertion loss, it is usually more effective to increase barrier height by a certain amount rather than to add a T-top of the same size.
3. Good agreement was obtained between measured and calculated sound levels. This tends to verify the applicability of the prediction procedure, based on the STAMINA 2.0 computer program and the application of geometrical acoustics, for parallel barrier calculations.
4. Based on calculations, the sound-absorptive treatment on the residential side provides only a limited benefit because it does not extend to the ground. The amount and the placement of the absorptive treatment on the freeway and residential sides should be optimized to achieve maximum acoustical effectiveness.
5. Sound levels at locations about 350 m from the highway centerline were unaffected by the barrier construction.
6. Aesthetically, the addition of a T-top does not appear to degrade the appearance of the conventional barrier.

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