rate was computed for a 1.6-km (1-mile) section, using the accident records for that category. Future ADT was estimated for each of the next 30 years, using both 2 and 5 percent annual traffic growth. The 30-year period was estimated to be a reasonable interval during which no major reconstruction would likely be required. For each of the 30 years, a cumulative summation of costs and benefits was made under each combination of assumptions about traffic growth, interest rate, and initial cost difference. Accident rate was assumed constant over the 30 years.

Figures 1 and 2 illustrate the general features of the analysis. Traffic growth is 2 percent annually for both figures. The point at which the curve crosses the horizontal axis is the year in which the savings due to accident reductions would repay the added cost associated with the wider paved road. Comparison between the two figures illustrates that the analysis is somewhat sensitive to changes in the economic value assigned to each injury or fatality accident. A condensed form of data presentation was used in evaluating the results of the computations. This is illustrated in Table 5 for one set of conditions.

CONCLUSIONS

Using the foregoing type of analysis, a table of suggested minimum paved widths was prepared. Table 6 compares the suggested minimums with existing Idaho Division of Highways standards. Because the analysis is relatively sensitive to injury or fatality accident cost, the suggested minimums should be reevaluated if the average cost of such accidents increases significantly, or if accident trends change significantly.

ACKNOWLEDGMENTS

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Earth Berms and Their Actual and Perceived Effects on Noise and Privacy in Adjacent Neighborhoods

Kumares C. Sinha, School of Civil Engineering, Purdue University, West Lafayette, Indiana
Neil R. Wienser, Milwaukee District, Wisconsin Division of Highways

The purpose of this paper is to compare and assess the measured and calculated attenuations obtained from earthen sound berms and also to assess the perceived effects of selected berms on adjacent residential neighborhoods by means of an attitudinal survey. Simultaneous sound readings were taken before and after construction of the berms. It was found that they produced median sound-level attenuations of 5 dB(A) at the right-of-way line and 3 dB(A) at a distance corresponding to the front sidewalk of the homes along the freeway. The attitudinal survey, conducted before and after the construction of sound berms, indicated that residents immediately adjacent to the freeway perceived a reduction in sound levels and increased privacy both indoors and outdoors. The study concluded that even minor attenuations of freeway noise of 5 dB(A) or less are discernible within adjacent neighborhoods and, based on the subjective responses of the attitudinal survey, are perceived to be greater than actually measured. Also, the increased privacy afforded by sound berms should be a consideration in the evaluation of proposals for the construction of future sound-attenuating devices.

In the fall of 1971 the Milwaukee metropolitan district office of the Wisconsin Division of Highways undertook a series of safety improvement projects, particularly concrete median barriers, on the interstate freeways within its jurisdiction. During the design of these barriers it became evident that there would be an excessive amount of earth material that would have to be removed from the project sites. It was decided that, rather than waste this material on private dumping areas, it could be used to develop experimental acoustical barriers at selected sites along the freeway that were near the sites. It was felt that the barriers would serve two purposes: They could be used as sound deflectors to reduce freeway noise levels for land uses along the freeway and they could function as privacy shields between the freeway and the adjacent land developments.

Because the use of such berms was experimental, it was felt that a study should be done to obtain first-hand information on the benefits and design of these barriers. Consequently, a before-and-after study was undertaken to determine the effectiveness of the earth berms in sound attenuation and to serve as a guide for future design and construction of these devices.

The initial intent of the before-and-after study was a series of sound-level readings to measure the actual attenuation realized from the barriers. However, a literature search revealed a number of studies that had already measured attenuation of barriers of this nature (1, 2, 3, 4). All of these studies, nevertheless, indicated

Figure 1. Typical earth berm cross sections.

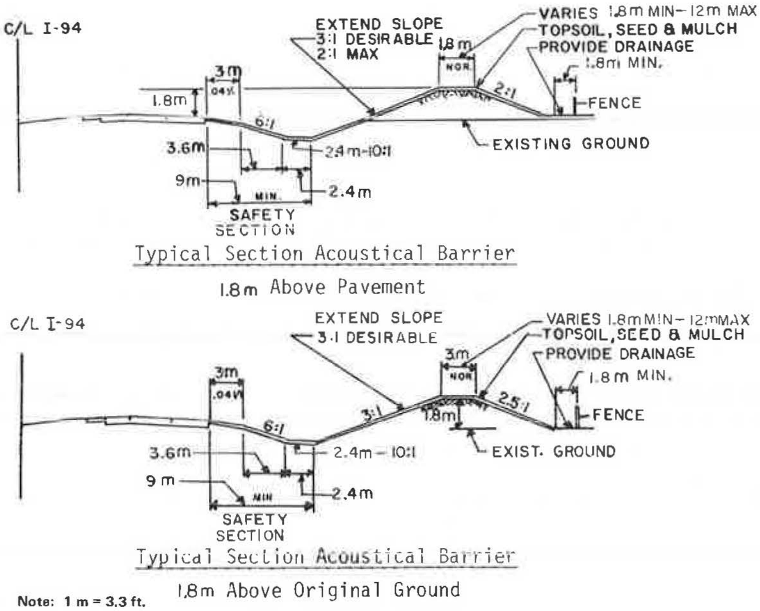
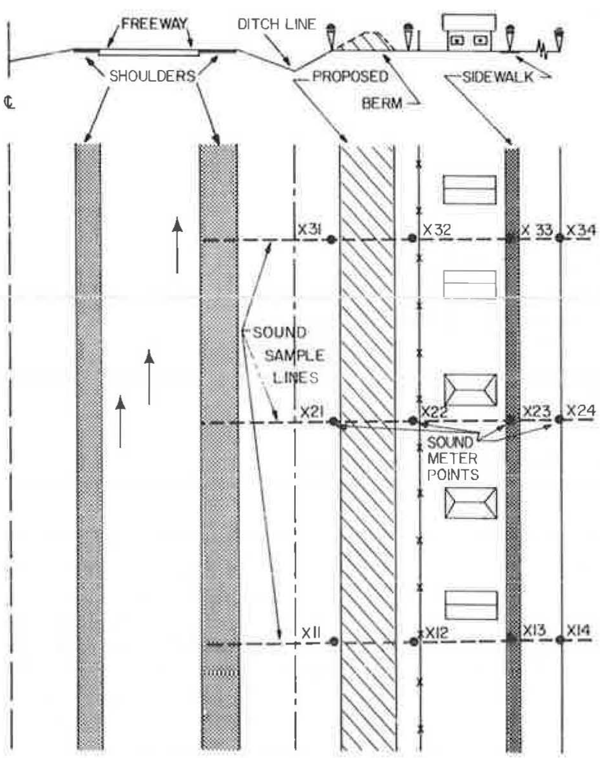


Figure 2. Typical sound sample and point location.



that, although measured attenuations were well documented, there appeared to be a lack of information concerning the perceived attenuation and the acceptance of such barriers by the adjacent land users. Furthermore, it was felt that even if the barriers did not afford a significant amount of attenuation they would provide privacy to the adjacent neighborhoods. It was therefore decided to conduct a thorough study (6) that would not only measure the resulting attenuation of these barriers through a series of simultaneous before-and-after sound-level readings, but that would also produce information concerning the perceived effects and acceptance of the barriers by the residents in adjacent neighborhoods, through an attitudinal survey, to be administered before and after the construction of the barriers.

SOUND-BARRIER DEVELOPMENT

The earth berms were constructed entirely on existing highway right-of-way land. Six sites were located along the North-South Freeway, I-94, in Milwaukee County. Because the safety improvement projects were extended to a portion of the East-West Freeway in Waukesha County, two additional barrier sites for construction of acoustical barriers were selected.

As the material became available for construction of each berm from the excavation for the median safety barriers on the freeways, it was put in place. The contractor responsible for a few of the berms decided to construct the center of the berm with removed concrete curb and gutter. This material was covered with the adequate earth material taken from the median area of the adjacent freeway. It was intended, in the location of each barrier, that the haul distance for the median soil be kept to a minimum.

In Figure 1 typical cross sections of the sound berms constructed are shown. Actual design in a specific site depended upon several factors, including considering the continuation of existing slopes, minimum width of a relatively level top, and maximum slopes for safe maintenance. Minimum distances from right-of-way fences for any future maintenance vehicles were also taken into consideration. In addition, adequate provision had to be made in the berm design for proper cross drainage of trapped water. A thorough landscaping plan was developed that included not only seeding but also extensive placement of bushes and trees. Before the placement of any berms, existing trees and bushes were carefully removed from the areas and preserved for use in the final landscaping.

The landscaping plan primarily included fast-growing species of bushes that could be planted in drifts rather than singly. The landscaping was completed in the spring of 1973, the year after berm construction. Because the plants used in landscaping were very young and the bushes that were removed and later replanted on the berms had only been planted in recent years and were not yet mature, the immediate impression of landscaping did not appear extensive. However, over the next several years the full extent of the landscape work will become evident as the plants and bushes reach their maturity.

FIELD MEASUREMENTS OF SOUND BEFORE CONSTRUCTION

A sampling procedure was developed through several trial methods that could be followed by field technicians and that was subsequently shown to be accurate to ±1.75 dB(A) at a 95 percent confidence level. Along with the measuring of changing sound levels, traffic volume and classification were also recorded.

While the adopted sampling method measured a sound level at any one point, it could not be used to measure an attenuation at a single location on a before-and-after survey because it is nearly impossible to duplicate the sound source that existed during the initial survey. Therefore, measured attenuation was obtained through simultaneous readings at fixed points from the freeway that included points along the freeway side of the future berm and several points on the other side of the berm at various distances away from the freeway. Figure 2 shows a layout of typical sound-sample lines and point locations.

This method in the initial survey produced attenuations that reflected changes in sound levels due to distance and other terrain parameters. In the after survey the measured attenuations with the addition of the barrier between the sound source and the observers beyond the barrier, with the distance and other terrain parameters unchanged, were compared to the initial attenuations. The comparison between the before-and-after attenuations resulted in the attenuation caused by the introduction of the earth berm in the path of the sound.

All sets of sound-level readings were taken simultaneously in order to negate the effect of changing the traffic parameters. It was observed that along the freeway the sound levels varied from 80 to 86 dB(A) on the North-South Freeway and from 84 to 88 dB(A) on the East-West Freeway at the edge of roadway. Corresponding sound ranges at point 2 were 74-80 dB(A) and 78 dB(A) without variation; at point 3 the range varied from 60 to 75 dB(A) and from 66 to 71 dB(A); and at point 4, which was measured on the North-South Freeway only, the range varied from 54 to 68 dB(A).

It can be seen from the difference in the ranges that, although the same identical traffic did not pass during each of the sample periods on a sample line, the L_{10} sound level remained fairly uniform along the freeway but a greater range was observed at the more distant locations. It may be noted that the sound levels farther from the freeway appeared to be more susceptible to activities within the neighborhoods—children playing, subdivision traffic, and lawn care.

FIELD MEASUREMENTS OF SOUND AFTER CONSTRUCTION

The same procedures developed for the initial study were followed in the sound study after the berms were constructed.

In the after survey it was observed that along the freeway the sound levels varied from 81 to 88 dB(A); at point 2 the sound level varied from 68 to 79 dB(A); at point 3 the range was from 63 to 71 dB(A); and at point 4 the range went from 57 to 70 dB(A). Although the ranges of sound levels were sometimes higher in the after survey than in the before survey, this did not indicate a loss of attenuation due to the sound berms.

Traffic volumes and classification mix that were different during the final survey produced basic sound levels different from the initial survey. For proper consideration of sound attenuation the sound data were analyzed by comparing before-and-after sound readings from point 1 with those at the other sampling points along the sample line; this procedure does not allow the results to be affected by the variations in traffic volumes during, before, and after sound surveys.

An established method (4) was used to calculate all sound-berm attenuations for a general check of measured values. These attenuations appeared to be satisfactory and generally what would be expected. Table 1 summarizes the measured and calculated attenuations obtained at location 4. The resulting median ambient sound level L_{10} at that location is given below (1 m = 3.3 ft):

	L_{10} by Distance to Edge of Near Freeway Lane [dB(A)]		
Condition	20-27 m (point 1)	40-53 m (point 3)	76-98 m (point 4)
Measured	72	63	65
Calculated	74	64	62

ATTITUDINAL SURVEY

Before Construction

The initial attitudinal survey was conducted before the berms were constructed to investigate the opinions of the residents in adjacent residential neighborhoods who would be affected by the future sound berms. The survey included a questionnaire constructed to judge the current attitudes on a number of neighborhood characteristics.

In addition to the future berm areas, the survey included a control area that would not be affected by the construction of future sound berms. By comparing the responses from the initial and final questionnaires, the control area information could be used as a basis for judging any outside influences during the period between the two surveys that might have caused an appreciable change in the attitudes of the residents of the study area.

Identical questionnaires were handed out in both the control and study areas. The questionnaires were designed to be cross checking; that is, the opinions concerning the effects and extent of freeway noise in the neighborhood were asked in several different questions. In this way it was felt the consistency and validity of the responses could be checked.

Because it was believed at the beginning of the survey that the berms would provide not only a sound attenuation for the adjacent neighborhoods but also increased privacy for the residents, several questions were included that would evaluate the respondents' attitudes toward the possible invasion of their privacy by the adjacent freeway. The survey questionnaires and a summary of the responses to the questions are available elsewhere (6).

Five of the eight proposed sound berms were located immediately adjacent to residential subdivisions. Three of these berms were located so that they would affect approximately 415 dwelling units. The control area included approximately 195 dwelling units. In Figure 3 is shown the aerial view of the sound berm along I-94. A review of the 1970 census information showed that the age of the survey area population was predominantly in the range of 25-40 years. Valuation of the homes ranged from $24 000 to $34 000.

The survey questionnaires were delivered personally by the study group and were collected after a few days from the respondents at their homes. A cover letter in-

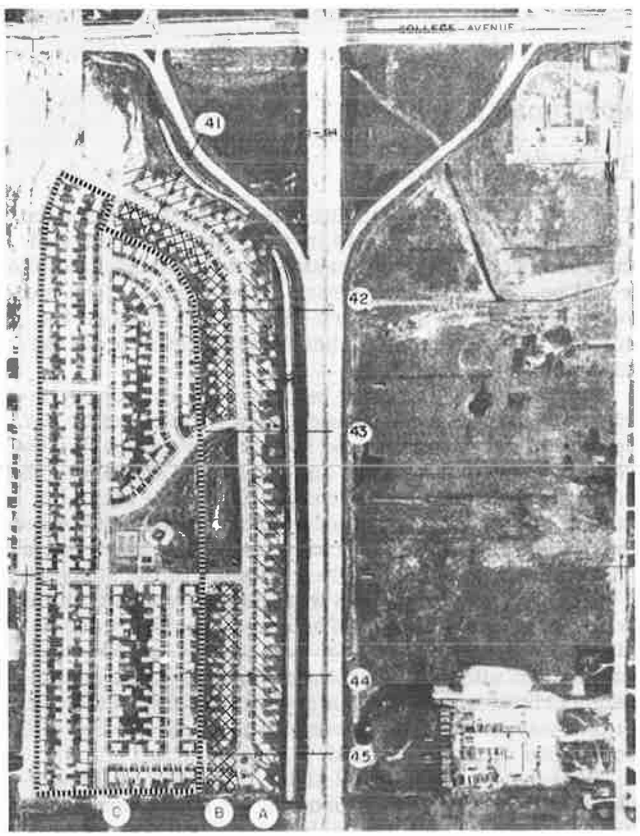
Table 1. Attenuation L_{10} in dB(A) for 2680-4480 vehicles/h and 20 percent trucks.

Line	Type of Attenuation	Attenuation by Distance to Edge of Near Freeway Lane [dB(A)] 20-27 m (point 2)	40-53 m (point 3)	76-98 m (point 4)	Barrier Height (m)	Distance to Nearest End of Berm (m)
41	Measured	5	5	1	2.9	24.4[a]
	Calculated	6	4	1		
42	Measured	9	17	14	1.8	18.3
	Calculated	11	8	6		
43	Measured	7	8	4	1.7	21.3
	Calculated	10	7	3		
44	Measured	2	4	2	1.5	43.0[a]
	Calculated	5	3	1		
45	Measured	1	-3	-3	3.1	12.2
	Calculated	0	2	1		

Note: 1 m = 3.3 ft.

[a]Break in barrier between sound sample lines.

Figure 3. Alignment of tiers in study area.



formed the respondents of the nature of the survey, why it was being conducted, and how the completed survey forms would be collected. A total of 417 questionnaires were distributed in the study area; the response rate was 45 percent. At the control area, 195 questionnaires were distributed; the response rate was 32 percent.

In the development of the attitudinal survey it was felt that responses would be different depending on the location of the respondent in relation to the freeway. Accordingly, a record was kept to indicate the location of the home of each respondent; the locations are identified as tier A if the homes are situated directly adjacent to the freeway, tier B if the homes are situated one lot away from the freeway, and tier C if the homes are situated at two or more lots away from the freeway. The responses to the questions relevant for this study were summarized by the location of tiers. The alignment of tiers in the area is shown in Figure 3.

The survey showed 63 percent of the respondents in the study area and 83 percent in the control area moved into their homes during or after the construction of the freeway. The percentage of the respondents who indicated that they were either "very satisfied" or "just satisfied" living in the study area and control area are 92 percent and 81 percent respectively. The majority of the respondents in both the study and control areas considered their neighborhood to be "noisy" or "slightly noisy". The location in the study area within tiers A, B, or C was found to be significant with respect to the responses to neighborhood noise. A chi-square test with grouped data indicated no significant difference in the responses from the study and control areas. All tests were conducted with a 1 percent level of significance.

Table 2 presents the responses obtained from the study area with respect to the question on "noticing noise". Through chi-square tests it was observed that, although the perception of noise inside the home was not significant with the location of tier, it was significant outside the home. This result can be attributed to the sound attenuation offered by the dwelling unit.

The respondents were observed to be annoyed by the freeway traffic noise, and again this annoyance varied significantly from tier to tier. Table 3 shows the degree of annoyance by freeway traffic noise in the study area.

In general, the respondents felt they had "enough privacy"; however, as shown in Table 4, there was some lack of privacy resulting from the layout of houses, lack of bushes and trees, and freeway exposure. As expected, the lack of privacy due to freeway exposure was significantly affected by tier location with respect to freeway.

After Construction

The final attitudinal survey was conducted in October 1973 in the same manner as the initial survey. However, the questionnaires were modified to include questions concerning the berms that had been placed in the study area in the meantime. Out of a total of 494, 156 responses were obtained in the study area, while in the control area 93 questionnaires were returned out of 210.

In the study area 53 percent of the respondents felt that the sound berms were effective in reducing traffic noises heard out of doors in their neighborhoods. This was slightly higher, 58 percent, in tier A than for the entire study area. Indoors, 52 percent felt that the sound berms were effective in reducing freeway noise; there was an increase in this response in tier A from the out-of-doors results in that 66 percent felt that there was a decrease in noise. The tabulation of the responses is shown in Table 5.

With respect to privacy, 68 percent of the respondents in tier A of the study area and 28 percent of the total respondents felt that there was an increase in household out-of-doors privacy due to the berms. This result is entirely understandable considering that generally privacy would be affected mainly for the respondents adjacent to the freeway or, at the most, one tier of lots removed from the freeway. The indoors response indicated that 55 percent of the respondents in tier A and 21 percent of the respondents overall felt there was an increase in indoor privacy. The tabulation of the responses is shown in Table 6.

Fifty-four percent of the total respondents indicated that there was a positive effect from the berms. Moreover, the percentage of respondents in tier A who felt the berm had improved privacy and reduced noise was 71 percent. In analyzing the responses by tiers, tier C indicated that the predominant effect was less freeway noise, while in tier A both the reduction in freeway noise and the increased household privacy were mentioned as the predominant effect in approximately an equal number of responses.

Table 2. Perception of neighborhood noise.

Response	Outside Tier A	Outside Tier B	Outside Tier C	Outside Total	Inside Tier A	Inside Tier B	Inside Tier C	Inside Total
Not noticeable	2	0	5	7	4	4	28	36
Slightly noticeable	8	4	49	61	23	17	53	93
Very noticeable	25	31	60	116	5	12	25	42
Total	35	35	114	184	32	33	106	171

Table 3. Annoyance by freeway noise.

Response	Tier A	Tier B	Tier C	Total
Not annoyed	8	3	42	53
Slightly annoyed	10	18	38	66
Very annoyed	17	15	22	54
Total	35	36	102	173

Table 4. Neighborhood conditions negatively affecting personal privacy.

Response	Tier A	Tier B	Tier C	Total
Layout of houses	14	18	48	80
Lack of bushes and trees	13	8	31	52
Heavy traffic	6	2	8	16
Neighbors	5	10	18	33
Freeway exposure	19	8	10	37
Children	6	9	22	37
Others	1	2	10	13
Total	64	57	147	268

ATTITUDINAL SURVEY COMPARISONS IN CONTROL AREA

A detailed statistical comparison of the responses from the before-and-after surveys in the control area was made in order to determine any changes that might have affected responses in the study area as to the effects of the sound berms.

A series of chi-square tests was performed with respect to length of residence, respondent's satisfaction with neighborhood, the characteristics liked most and least, consideration of noise in the neighborhood, degree of annoyance from noise, consideration of privacy in the neighborhood, and sex and age group of the respondent. It was concluded that there had not been a statistically significant change in attitude concerning the noise or privacy level in the control area in the period between the two surveys.

As the study area was in the general vicinity of the control area it was felt that the responses related to the berms in the study area were not affected by any attitudinal changes since the initial survey. This conclusion was further validated by determining that the characteristics of the respondents in the study area did not change.

MEASURED ATTENUATION AND PERCEIVED EFFECTS

Sound levels are measured as decibels on the A scale. The decibel is a log measurement of sound intensity or acoustical energy. The relationship between sound-level change and acoustical energy and corresponding change of relative loudness (5) is shown below.

Sound-Level Change [dB(A)]	Acoustical Energy Loss (%)	Relative Loudness
0	0	Reference
-3	50	Perceptible change
-10	90	One-half as loud
-20	99	One-quarter as loud
-30	99.9	One-eighth as loud

To compare measured and perceived attenuation, further discussion of audible sounds is necessary. Peak hearing ability is observed during the ages of 10-20 years. Before that age hearing ability increases, and after it hearing ability decreases. During the peak hearing periods

Table 5. Effectiveness of berms on freeway noise reduction.

Response	Outside Tier A	Outside Tier B	Outside Tier C	Outside Total	Inside Tier A	Inside Tier B	Inside Tier C	Inside Total
Much less noise	4	1	8	13	7	3	16	26
Slightly less noise	18	12	38	68	18	9	28	55
No effect	15	11	39	65	9	13	43	65
Slightly more noise	-	1	2	3	1	1	1	3
Much more noise	1	3	1	5	3	2	1	6
Total	38	28	88	154	38	28	89	155

Table 6. Effectiveness of berms on increasing privacy.

Response	Outside Tier A	Outside Tier B	Outside Tier C	Outside Total	Inside Tier A	Inside Tier B	Inside Tier C	Inside Total
Much more privacy	12	3	2	17	8	1	2	11
Slightly more privacy	14	3	8	25	13	2	5	20
No effect	9	20	71	100	13	23	74	110
Slightly less privacy	2	1	3	6	3	-	3	6
Much less privacy	1	1	-	2	1	2	-	3
Other	-	-	1	1	-	-	1	1
Total	38	28	85	151	38	28	85	151

Table 7. Study area attenuation L_{10} in dB(A) for 2680-6790 vehicles/h and 11-20 percent trucks.

Type	Attenuation by Distance From Freeway [dB(A)] 20-43 m (point 2)	40-125 m (point 3)	76-98 m (point 4)	Berm Height (m)
Median				
Measured	5	3	1	2.1
Calculated	5	2	1	
Range				
Measured	1-10	0-8	0-6	1.5-4.3
Calculated	0-11	1-8	0-6	

Note: 1 m = 3.3 ft.

humans can distinguish intensity of noise difference of 2-3 dB(A). After the age of peak hearing, a 3-4 dB(A) intensity difference is required for the normal person to distinguish a difference in sound levels. When a person is not looking for the difference in sound levels, the change in level would have to be in the range of 4-6 dB(A) to notice the difference.

COMPARISON OF SOUND-LEVEL ATTENUATION

The final attitudinal survey in the study area obtained the subjective attitude of the respondents in relation to the decrease in neighborhood noise attributable to the sound berm. In tier A, 47 percent indicated "slightly less noise", 11 percent indicated "much less noise". Based on the definition of audible sound it can be concluded that "slightly less noise" could correspond to a sound that is audible to a typical respondent in the 30-40 age bracket, in the range of 4-6 dB(A). "Much less noise" can be considered to be in the range of 8-10 dB(A). In tier B, 33 percent indicated a "slightly less noise" response. This could also correspond to a 4-6 dB(A) reduction in noise level at tier B.

Table 7 summarizes the measured and calculated attenuations within the study area. The calculated attenuations were derived on the basis of the procedure given elsewhere (4).

A review of the above measured attenuations with the subjective responses indicated that the respondents to the survey felt that there was a slightly greater attenuation than shown in the measured survey. Approximately half (47 percent) of the respondents in tier A indicated that there was a 4-6 dB(A) reduction in noise for their living activities, whereas the measured attenuations indicate that, while at the right-of-way line there was a median attenuation of 5 dB(A), the attenuations at the sidewalk line were 3 dB(A). This is slightly less than the subjective attitudinal attenuations. Also, 11 percent indicated "much less noise", which is somewhat higher than the actual attenuation. In tier B, 33 percent indicated a "slightly less noise" attenuation of 4-6 dB(A); however, the measured attenuations indicated a median attenuation at approximately the sidewalk line of tier B of 1 dB(A), indicating that there was a perceived or subjective attitudinal attenuation for a third of the respondents in tier B of approximately 3-5 dB(A) higher than the measured attenuation.

This comparison indicates that a berm of the given design and layout would give an attitudinal attenuation slightly higher than what would be obtained in reality. This would mean that, although a berm would be expected to result in a relatively small calculated attenuation, the benefit achieved in the minds of the people affected would be potentially greater. This is important because even a slight anticipated attenuation could be considered worthwhile as an overall effect.

PRIVACY CONSIDERATION

The attitudinal survey in the study area after the berms were constructed indicated that 68 percent of the respondents in tier A felt that they had experienced an increase in privacy in their neighborhood because of the sound berms. The majority of the responses indicating a positive "most significant effect of the sound berms" in tier A was related to both freeway noise and increased household privacy with some additional responses indicating just "increased household privacy" as a most significant effect. It can, therefore, be concluded that the increased household privacy is a major benefit to the residents in tier A who are, in fact, the households most affected by the freeway.

DESIGN CONSIDERATIONS

A series of photographs was taken at various points in the study area before and after the construction of the sound berms. A review of these photographs indicated that, after the berms were placed, the tops of the adjacent homes could be seen from the freeway but the direct line of sight for a person standing on his or her property was blocked from the freeway. Observations made from within the study area after the berms were placed indicated that the tops of heavy trucks and their exhaust systems were visible from the adjacent properties.

The result of the attitudinal survey revealed that 69 percent of the respondents in tier A and 49 percent of all respondents felt that the berm should have been constructed higher. Of these responses 70 percent in tier A and 65 percent in all tiers indicated that the berms should have been constructed 0.61-1.8 m (2-6 ft) higher. The computations done on calculated attenuations showed that this additional height would have increased attenuation by 2-4 additional decibels, resulting in the median attenuation of 8 dB(A) for the residents in the adjacent area.

In the design factors it appears that berms should be constructed with regard to the adjacent land use considering the height of development occupying that land, in order to separate the entire development from freeway sight. Also, reductions or breaks in the berm should be given careful consideration, as they adversely affect its overall usefulness.

CONCLUSIONS

A group of major conclusions can be drawn from this study. These conclusions are discussed in the following paragraphs.

1. A measured and calculated median attenuation of 5 dB(A) was obtained for the sound berms in this study; the range of attenuation was 1-10 dB(A).
2. The attitudinal responses related to the effect of sound berms on noise compared well with the measured levels of attenuation. However, it appeared that the perceived attenuations tended to be higher than measured values, indicating that people affected by sound berms judged the benefits to be greater than actually measured.
3. An important consideration in the location of sound barriers should be an increase in privacy for the adjacent land users. This was indicated in the attitudinal survey and should be given equal consideration when only minimum noise attenuation is anticipated from a proposed sound barrier, resulting in questionable justification for construction.
4. On existing freeways the cost of sound berms as a prime item of a construction contract appears to be

significantly high. However, if material is available from nearby freeway construction improvement work and the cost of material removal from the right-of-way is anticipated to be high, construction of sound berms appears to be a desirable highway policy.

5. Sound barriers should be designed and constructed with major consideration for the topography of the freeway and adjacent land, for the existing or planned development of the neighboring land, and for the effects of height and length of the barriers on anticipated results.

6. From the negative comments concerning berm construction it was concluded that sufficient public relations should be performed in the development stage of sound barriers to obtain sufficient information to properly locate the barriers and inform the public of anticipated results of the barriers.

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Abridgment

Hydraulic and Safety Characteristics of Selected Grate Inlets

P. H. Burgi, U.S. Bureau of Reclamation, Denver
D. E. Gober, U.S. Forest Service, Laramie

With the recent increase in the number of bicycles on our nation's highways and streets, there has been a corresponding increase in the number of bicycle accidents. Some of these accidents are related to highway grate inlets. The purpose of the comprehensive study summarized in this paper was to identify, develop, and analyze selected grate inlets that maximize hydraulic efficiency and bicycle safety.

Fifteen grate inlet designs were initially selected for consideration. They included seven steel-fabricated grates and eight cast grates.

The test program was conducted using two test facilities. The bicycle safety tests were conducted on an outdoor test site consisting of a 6.7-m (22-ft) wide, 152-m (500-ft) long abandoned roadway. A 2.44-m (8-ft) wide, 18.3-m (60-ft) long hydraulic test flume was constructed in the U.S. Bureau of Reclamation, Hydraulic Research Laboratory, and used as a test facility for the hydraulic efficiency tests.

ANALYSIS OF STRUCTURAL INTEGRITY

Figure 1 illustrates the basic grate inlet designs that were structurally analyzed and the reticuline grate that was not structurally analyzed because it is commercially available and the manufacturer's publications provide vehicle load tables based on AASHTO specifications.

The general-purpose computer program STR5 was used to perform the structural analysis of the selected grates. In some cases it was determined by a preliminary analysis that the bearing bars of the grate acted independently as simple supported beams. In those cases, a simple beam analysis was performed.

The grates tested have been code-named to standardize the names. The first symbol refers to the grate design (parallel bar grate P, curved vane grate CV, 45° or 30° tilt bar grate 45 or 30, and reticuline R). The second number is the nominal center-to-center longitudinal bar spacing. The last number is the nominal center-to-center transverse bar spacing. Therefore, the P-48-102 (P-1⅞-4) grate refers to a parallel bar grate with center-to-center spacing of the longitudinal bars of 48 mm (1⅞ in) and center-to-center spacing of the transverse bars of 102 mm (4 in).

ANALYSIS OF BICYCLE AND PEDESTRIAN SAFETY

Bicycle and pedestrian safety tests were performed on 11 grate inlets to preselect safe grate inlets for the hydraulic testing phase of the study. The grate size of 0.61 × 1.22 m (2 × 4 ft) was selected for use in the bicycle safety tests. Table 1 presents principal features of the grates evaluated in the test program and gives their bicycle safety rankings.

Two grates were tested in the hydraulic efficiency tests that were not tested in the bicycle safety tests. The curved vane grate CV-83-108 (CV-3¼-4¼) design was very similar to the 45-83-102 (45-3¼-4) grate, which satisfactorily passed the bicycle safety tests. The parallel bar grate with transverse spacers P-29 (P-1⅛) was tested independently for bicycle safety (1).

The transverse spacing of grate bars is a critical factor in bicycle safety performance. It is a more critical factor than whether the grate is of the reticuline, 45° tilt bar, curved vane, or parallel bar with