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NOISE BARRIER DESIGN HANDBOOK

HIGHWAY NOISE

Prepared for:

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

This handbook is intended to be a tool for use by the highway designer to aid in the design of noise abatement barriers. It provides a means of defining the geometric configuration of a barrier to produce a desired noise reduction, and also provides a design evaluation and selection procedure in which specific barriers are detailed, and then evaluated in terms of cost, acoustical characteristics, and non-acoustical characteristics (such as durability, ease of maintenance, safety, aesthetics and community acceptance). This handbook guides the designer in the preparation of a design which he believes will be accepted by the community and perform as desired both acoustically and non-acoustically, for reasonable cost.

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ADDENDUM

The barrier design curve presented in this manual has been approved for use on Federal-aid highway projects. Except at large Fresnel numbers, there are no practical differences between this curve and the other approved design curves (the NCHRP 117/144, and the Transportation Systems Center Noise Prediction Model) as illustrated in the figure below. The differences among the curves at large Fresnel numbers reflect the application of attenuation limits based on field experiences of the particular curve's author.

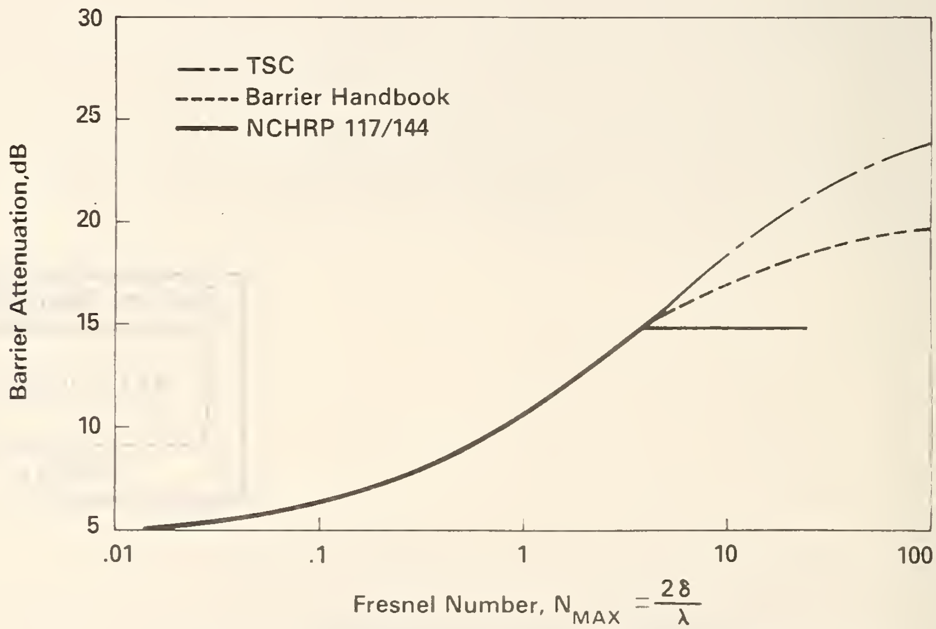

Figure 1. Comparison of approved barrier attenuation curves for incoherent line source.

PREFACE

This Handbook is the result of research and development conducted for the Federal Highway Administration under Contract No. DOT-FH-11-8287 by Bolt Beranek and Newman Inc., with the firm of Wilsey and Ham as subcontractor. Myles A. Simpson has been the Principal Investigator.

Within BBN, the following individuals made major contributions. David A. Towers was primarily responsible for obtaining and analyzing information on existing barrier constructions throughout the country, as compiled in Reference 1-1. The field evaluation study of barrier attenuation reported in Reference 1-2 was conducted by Myles A. Simpson, with assistance from David A. Towers and Harry Siedman. Daniel E. Commins performed the literature review also contained in that reference. The scale model and analytical study of multiple reflections in walled highways and tunnels, described in Reference 1-3, was conducted by Dinesh R. Pejaver and John R. Shadley. Parker W. Hirtle, Neville A. Powers, and Carl J. Rosenberg investigated the sound absorption properties of various materials catalogued in Reference 1-4.

Wilsey and Ham had primary responsibility for consideration of cost and non-acoustical characteristics of barriers, and for development of the reference drawings contained in this Handbook. Kenneth L. Wuest and Steven Vartan were principal participants from Wilsey and Ham.

During the course of this project, Dr. Eugene Chen, Dr. Howard Jongedyk and Dr. Timothy Barry have been Contract Managers. The author would like to thank them for their support and guidance throughout the project. Appreciation is also due to personnel from the Offices of Engineering, Environmental Policy and Implementation for their useful comments and suggestions.

Finally, the author would like to express his sincere gratitude to Grant S. Anderson and B. Andrew Kugler for their assistance, guidance and encouragement throughout the project.

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CHAPTER 1
INTRODUCTION

In recent years, increasing traffic flow on the nation's highways coupled with growing public awareness of environmental issues have established the need to evaluate the noise impact of new or existing highway configurations on neighboring communities. When the anticipated or current noise exposure exceeds desirable limits, there is both community pressure and governmental mandate to take the necessary steps to prevent or alleviate the noise problem.

Depending upon the severity of the problem, and the stage in which it is discovered, there are a variety of measures that might be taken to reduce highway noise impact. These measures are generally related to control of motor vehicle noise sources (such as traffic management and enforcement of vehicle noise regulations), modification of the highway configuration (such as relocation of the highway or use of elevated or depressed sections or noise barriers), and changes in receiver sensitivity (such as sound insulation or compatible land-use planning). Solution of a highway noise problem should involve a comprehensive analysis of all available options, and selection of those measures which in conjunction with one another provide the most desirable approach.

This handbook deals with just one of these noise abatement measures, the use of noise barriers. Because of the widespread noise impact from existing facilities throughout the country, and the practical and cost constraints often imposed on projected facilities, the use of noise barriers is perhaps the most frequent method for controlling highway noise. Indeed, construction of noise barriers has increased dramatically in recent years, with projected construction showing even greater increases.

This handbook is intended to be a tool for use by the highway designer to aid in the design of noise abatement barriers. While it provides a means of defining the geometric configuration of a barrier to produce a desired noise reduction, it goes beyond that by providing a design evaluation and selection procedure in which specific barriers are detailed, and then evaluated in terms of cost, acoustical characteristics, and non-acoustical characteristics (such as durability, ease of maintenance, safety, aesthetics and community acceptance). This handbook thus guides the designer in the preparation of a design which he believes will be accepted by the community and perform as desired both acoustically and non-acoustically, for reasonable cost.

As described in this handbook, the term "noise barrier" includes vertical walls, earth berms, and combinations of the two. Of course, the lip of an elevated highway or the top of the cut of a depressed highway may also serve as a noise barrier. Although these are not specifically addressed herein, the information that follows may be applied as appropriate to the evaluation of these configurations as barrier design alternatives.

Chapter 2 provides a discussion of barrier noise reduction concepts. Chapter 3 describes various acoustical and non-acoustical factors which must be considered in the design of a noise barrier, and provides much of the background for the design procedure contained in Chapter 4. The design procedure is a step-by-step process in which alternative barrier designs are developed and evaluated, followed by selection of an "optimum" barrier for the site under consideration. Chapter 5 provides examples of the design procedure. Appendices A, B and C contain reference drawings of noise barriers constructed of different materials and treatments. Finally, in Appendix D the design procedure of Chapter 4 is applied to five existing barriers, to further illustrate the design steps and the types of results attainable.

This handbook should be used in conjunction with other tools available to the highway designer for predicting noise exposure, defining criteria, assessing noise impact, and describing other means of noise control. In addition, for those interested in gaining a better understanding of the concepts underlying barrier design, four companion technical reports have been prepared. "Noise Barrier Attenuation: Theory and Field Experience" (Reference 1-1) contains a detailed discussion of the development of barrier attenuation theory, and the various predictive methodologies which have developed from the theory. Included also are the results of a field evaluation study involving ten barriers located across the country. Finally, the volume contains a comparison of barrier attenuation predictions with state highway department measurement experiences.

"Noise Barrier Catalogue" (Reference 1-2) documents existing barriers located throughout the United States in terms of their physical dimensions, acoustical performance, and design considerations.

The remaining two reports are both concerned with the application of absorptive materials on highways to reduce the noise exposure resulting from multiple reflections. "A Study of Multiple Sound Reflections in Walled Highways and Tunnels" (Reference 1-3) discusses an analytical and scale-model development of predictive procedures to evaluate the effects of reflected sound energy, and the benefits that might accrue from use of absorptive material to reduce these reflections. "Catalogue of Sound Absorbing Treatments for Highway Structures" (Reference 1-4) documents those materials that have been studied for use as sound absorbers in the highway situation.

CHAPTER 2
BARRIER NOISE REDUCTION CONCEPTS

An understanding of the acoustical principals which govern the noise reduction provided by a barrier is essential to the design of effective barriers. This chapter discusses the basic concepts of barrier noise reduction.

When no obstacles are present between the roadway and adjoining areas, sound travels by a direct path from "sources" on the roadway to "receivers" off the roadway, as shown in Figure 2-1. Introduction of a barrier between the source and receiver redistributes the sound energy into several paths: a diffracted path, over the top of the barrier; a transmitted path, through the barrier; and a reflected path, directed away from the receiver. These paths are also illustrated in Figure 2-1.

To properly define the complete effect of installing such a noise barrier, the sound energy along each of these paths must be taken into account, and compared with the sound energy along the original direct path. The contribution along each path will be individually discussed in the following sections.

2-1 Barrier Diffraction and Attenuation

Consider an infinitely long, infinitely massive noise barrier placed between the highway and the receiver. Figure 2-2 illustrates a cross-section through such a configuration. For this example, the only way that sound can reach the receiver is by bending over the top of the barrier; as shown in the figure, the sound reaching the receiver is bent through an angle ϕ. The bending of sound waves in this manner over an obstacle is known as diffraction. The area in which diffraction occurs

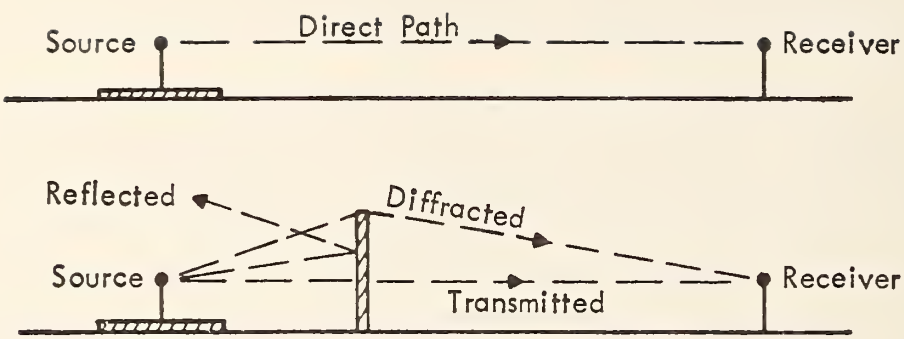


FIGURE 2-1 Alteration of Noise Paths by a Barrier.

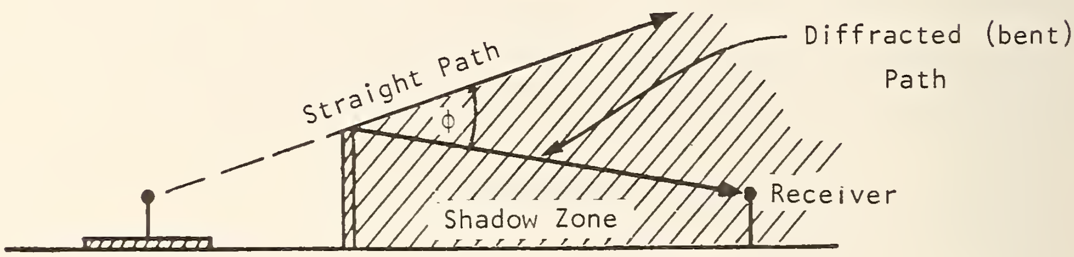


FIGURE 2-2 Barrier Diffraction.

behind the barrier is known as the "shadow zone." The straight path from the source over the top of the barrier forms the bounday of this zone.

All receivers located in the shadow zone will experience some sound attenuation; the amount of attenuation is directly related to the magnitude of the diffraction angle ϕ. As ϕ increases, the barrier attenuation increases. The angle ϕ will increase if the barrier height increases, or if the source or receiver are placed closer to the barrier. Clearly then the barrier attenuation is a function of the geometrical relationship between the source, receiver, and barrier. One way of relating these parameters to the barrier attenuation is to define the path-length difference δ as shown in Figure 2-3. This parameter is the difference in distance that the sound must travel in diffracting over the top of the barrier rather than passing directly through it.

By representing a highway as a line of incoherent (or unrelated) point sources, the relationship between the barrier attenuation and the path-length difference δ can be described as in Figure 2-4 (Reference 2-1). (Note that in this figure as well as in the remainder of this handbook, the symbol Δ will be used to represent attenuation. When necessary to distinguish barrier attenuation from attenuation due to other causes, the symbol Δ_B will be used.) The barrier attenuation Δ_B represented in Figure 2-4 is in units of dBA, and is applicable to the equivalent noise level L_{eq}. The equivalent level L_{eq} is an energy average of the A-weighted noise levels occurring over a specified period, such as an hour. For highways with moderately high vehicle volumes, $L_{10} \cong L_{eq} + 2$ dBA, when there is no shielding.

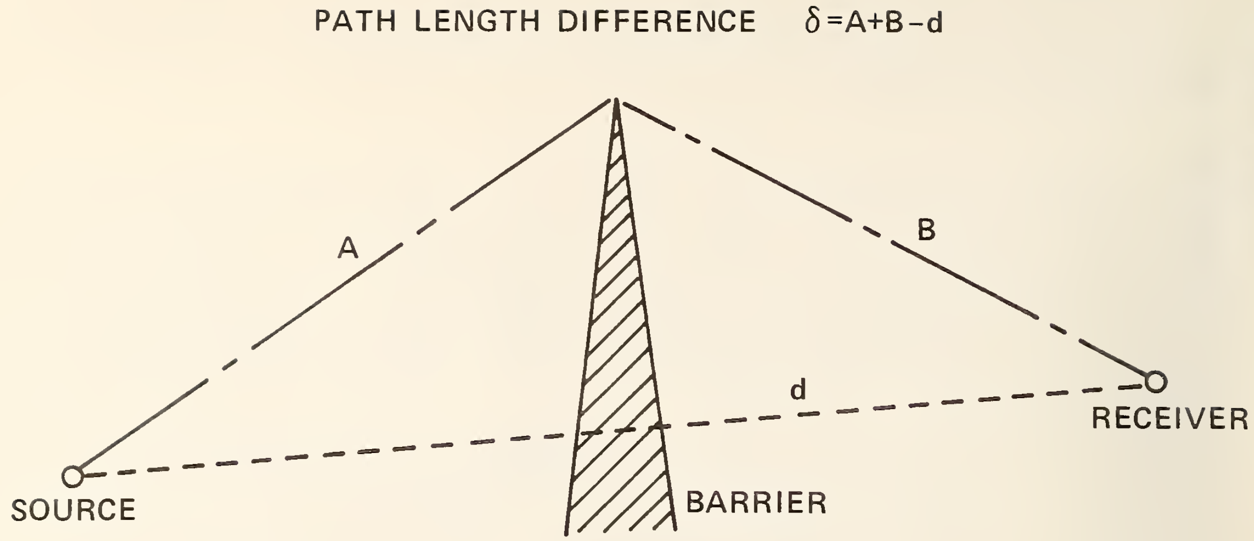


FIGURE 2-3 ILLUSTRATION OF PATH LENGTH DIFFERENCE.

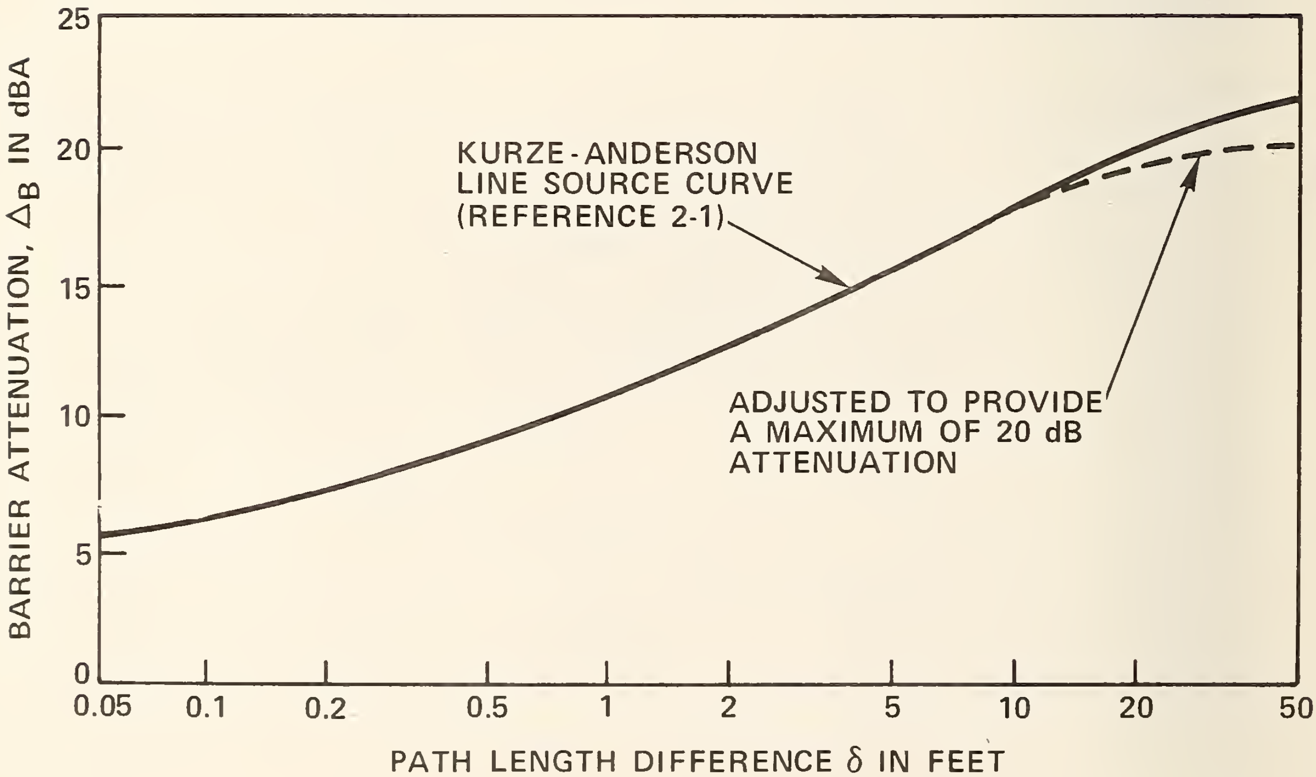


FIGURE 2-4 BARRIER ATTENUATION FOR A LINE OF INCOHERENT POINT SOURCES.

The attenuation of noise described in terms of L_{10} will be somewhat higher than for L_{eq} because L_{10} levels result from traffic on a smaller section of roadway than L_{eq} levels; the barrier is more effective on this smaller section than on larger sections. However, for most highway situations the difference between L_{10} and L_{eq} attenuation will be within 1 dB, and therefore Figure 2-4 is appropriate (if not slightly conservative) for L_{10} levels as well as L_{eq} levels.

The curve in Figure 2-4 (with maximum attenuation of 20 dB) has been converted to nomograph form (Reference 2-2) for ease of use, and is included as part of the design procedure of Chapter 4.

Note that in comparison with the attenuation prediction methodologies incorporated within the various analytical procedures currently available, the curve in Figure 2-4 and the nomograph in Chapter 4 provide attenuation values that are in good agreement with the predictions of the computer program of the Transportation System Center (Reference 2-3, hereinafter referred to as TSC), with the exception that TSC permits attenuation values higher than 20 dB. The methodology in NCHRP Reports 117 and 144 (References 2-4 and 2-5, hereinafter referred to as 117/144) provides comparable attenuations for car sources, but truncates the attenuation at 15 dB. For trucks, 3 dB is added to the car attenuation.

In the preceding discussion it was assumed that the barrier was "infinite"; i.e., long enough to shield the receiver from all sound sources up and down the highway. For short barriers, the attenuation can be seriously limited by the sound from sections of highway beyond the barrier's ends, which are unshielded from the receiver, as shown in Figure 2-5. Similarly, when there are

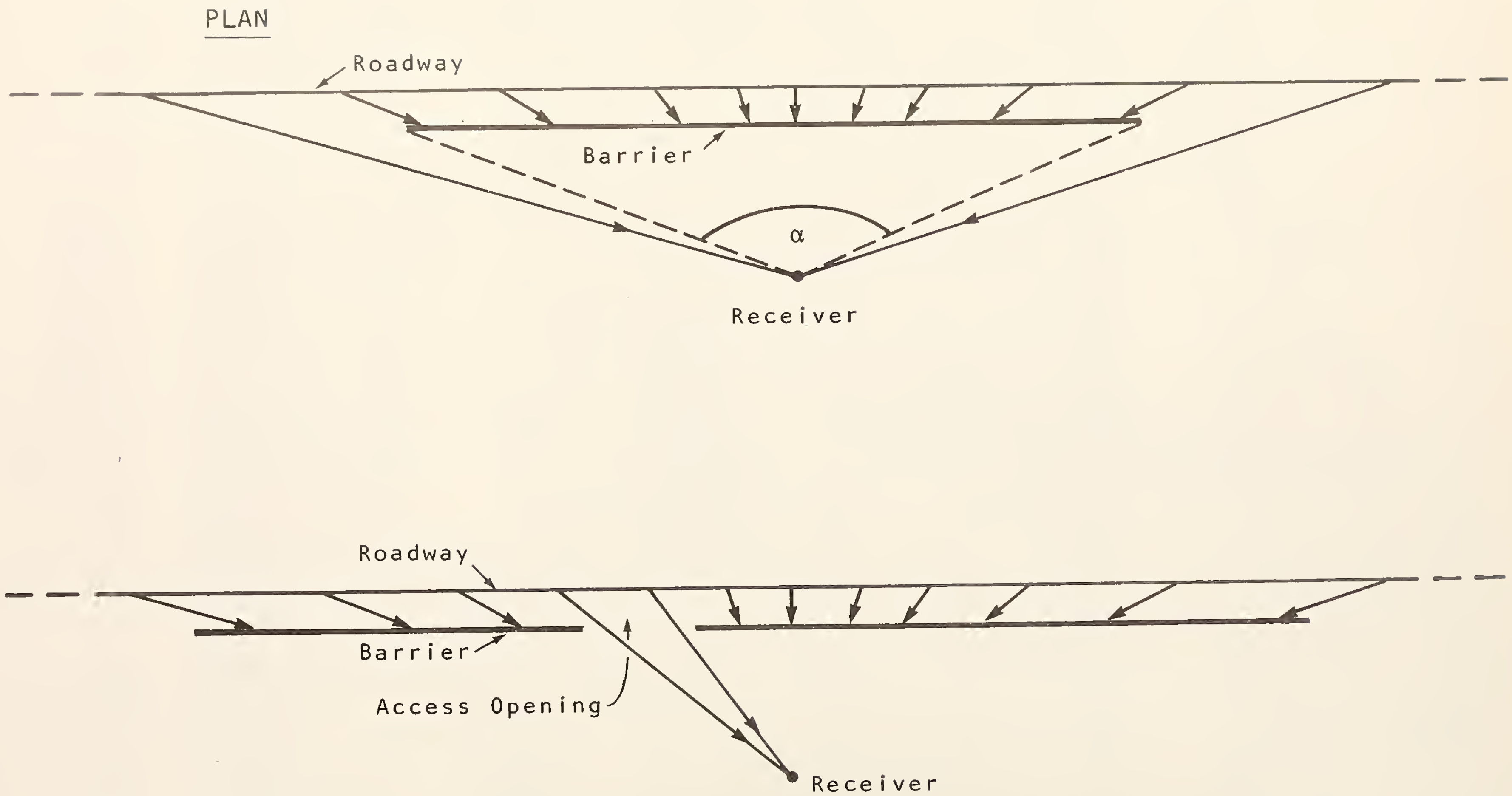


FIGURE 2-5 Short-Circuit of Barrier Around Ends and Through Openings.

large gaps in the barrier (to permit access, for example), sound from the unshielded section of highway adjacent to the gap can greatly compromise barrier attenuation, especially for those receivers close to the opening. The amount of shielding provided by a finite barrier can be related to the angle α subtended by the barrier (or by a section of a barrier). By summing the sound energy contributions from both shielded and unshielded sections of highway, the net attenuation due to the barrier can be determined as a function of barrier subtended angle. The nomograph in Chapter 4 permits evaluation of the barrier attenuation in terms of this angle.

2-2 Barrier Transmission

In addition to the sound that travels over the top of the barrier to reach the receiver, sound can travel through the barrier itself. The amount of "transmission" through the barrier depends upon factors relating to the barrier material (such as its weight, and stiffness and lost factors), the angle of incidence of the sound, and the frequency spectrum of the sound. One way of rating a material's ability to transmit noise is by the use of a quantity known as the transmission loss, TL. The TL is related to the ratio of the incident noise energy to the transmitted noise energy.

For spectra typical of highway noise sources, transmission loss values can be determined for specific types of materials. Chapter 4 provides TL values for a wide range of materials commonly used as noise barriers. Typically, the transmission loss improves with increasing surface weight of the material.

The noise reduction provided by a barrier can be severely compromised if the transmission loss of the material permits too much noise to pass through the barrier. As a general rule, if the transmission loss is at least 10 dB above the attenuation resulting from diffraction over the top of the barrier, the barrier noise reduction will not be significantly affected by transmission through the barrier (less than 0.5 dB). For many common materials used in barrier construction, such as concrete and masonry blocks, transmission loss values are usually more than adequate. For less massive materials such as steel, aluminum and wood, transmission loss values may not be adequate, particularly for those cases where large attenuations are required.

Even if a barrier material is massive enough to prevent significant sound transmission, the barrier noise reduction can be severely compromised if there are holes or openings in the barrier. For large openings, sound energy incident on the barrier will be directly transmitted through the opening to the receiver. When the opening is small an additional phenomenon occurs: upon striking the barrier wall the sound pressure will <u>increase</u> resulting in an amplification of the transmitted sound to the receiver. Thus, the presence of openings or holes may seriously degrade the noise reduction provided by otherwise effective barriers.

Note that the procedure in Chapter 4 provides details of the effects of inadequate transmission loss properties on the barrier noise reduction.

2-3 Barrier Reflections

As shown in Figure 2-1, sound energy can be reflected by a barrier wall. For the configuration shown in that figure, the reflected energy does not affect the receiver, but may affect receivers located to the left of the highway. However the increase in noise level for these receivers would be less than 3 dB, because this single reflection can at most double the sound energy.

The situation is entirely different, however, when a double barrier situation is involved (refer to Figure 2-6). In addition to the energy that reaches the receiver by diffraction over the top of the barrier, if the barrier walls are reflective additional sound energy can reach the receiver by a reflection from the right wall as illustrated in the figure. This energy can be conceived of as coming from an image source i_1, located to the right of the barrier. Similarly, there is still another image source, i_2, which results from the reflection of sound energy first from the barrier on the left and then the barrier on the right, and so on. Note that the same principles apply when there is a vertical retaining wall opposite a noise barrier; similarly, in a deep vertical cut the opposite walls will create multiple reflections.

The number of image sources which contribute significantly to the total sound level at a receiver is a function of receiver height. For example, if the receiver cannot see the far barrier, then an infinite number of image sources contribute to the total level because there are an infinite

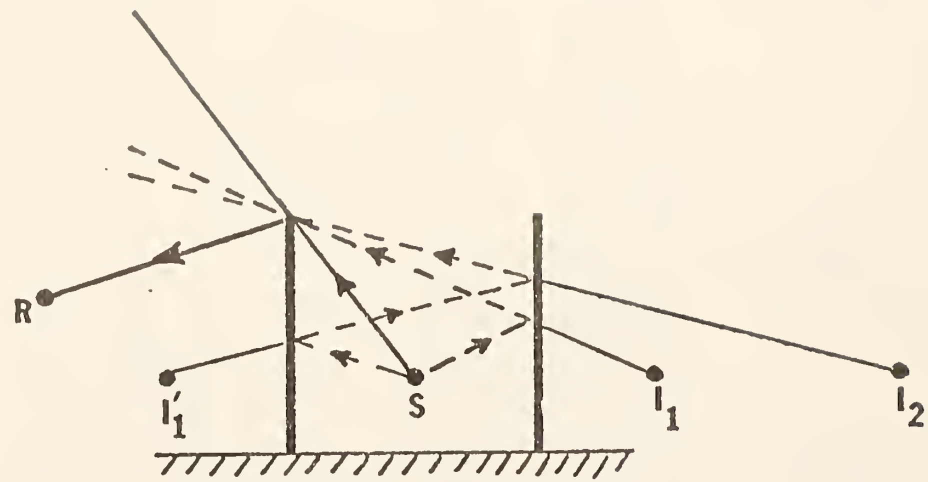


FIGURE 2-6 Multiple Sound Reflections for a Double - Walled Highway.

number of reflections. As the height of the receiver increases, the number of contributing image sources decreases, and the effectiveness of the near barrier decreases. Thus each reflection becomes relatively less important because the level of the source itself increases as the shielding is decreased. As the height is further increased, a point is reached where no reflections contribute to the level at the receiver.

One way of evaluating the effect of these multiple reflections is to consider the change in barrier attenuation resulting from the presence of the second barrier. The presence of the wall on the right of the highway will degrade the performance of the barrier on the left by an amount which can be called ΔBAR. ΔBAR is a function of receiver height, barrier height, highway width, and receiver distance to roadway.

However, if the barrier walls are not perfectly reflecting but absorb some of the sound energy, the contribution of each reflection is decreased by an amount that depends upon the absorptive characteristics of the barrier. The ratio of the acoustical energy absorbed by a material to the total energy incident upon that material is known as the absorption coefficient, usually denoted by the symbol α. For any particular material, the absorptive characteristics will be a function of frequency. In order to rate the overall absorptive characteristics of the material, a measure of the average absorption over the frequency range of interest is useful. An appropriate measure is the Noise Reduction Coefficient, NRC. The Noise Reduction Coefficient is the arithmetic average of the absorption coefficients in the four octave bands which cover the frequency range from approximately 200 to 3000 Hz:

$$NRC = \frac{1}{4}\left(\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}\right) \qquad (2\text{-}1)$$

For very hard reflective surfaces, the absorption coefficients (and thus NRC) are very small, nearly zero. For materials which absorb almost all of the incident energy, the absorption coefficients and the corresponding NRC are nearly one.

Although a serious degradation in barrier performance may result for the double barrier situation, use of materials with high NRC values will usually recover all of the lost noise reduction. A methodology for determining ΔBAR for hard reflective walls, as well as for walls lined with highly absorptive materials, is provided in Chapter 4.

It should be mentioned that the use of barrier walls with sloped sides (forming angles of greater than 10 - 15 degrees from the vertical) will also generally eliminate multiple reflections. Use of earth berms is particularly appropriate to accomplish this. Sloped barrier walls will require more material to achieve a desired height than a vertical wall, while berms will require greater right-of-way than a thin wall.

Note that the use of absorptive materials on single barrier walls generally provides no benefit. For diffraction angles greater than 45°, absorptive materials <u>can</u> influence the sound that is diffracted over the top of the barrier. However, in most highway situations it is rare to find a configuration in which the diffraction angle will approach that magnitude. For angles less than 45° use of absorptive materials is of little advantage in reducing noise levels.

2-4 Multiple Shielding Effects

The effects of sound diffraction over more than one barrier are not well understood. It is believed that for situations in which a barrier is placed between a roadway and rows of houses and/or significant stretches of vegetation which shield a receiver, the benefits of the barrier attenuation, house attenuation, and vegetation shielding may be additive. The current noise estimation procedures (TSC and 117/144) use this assumption.

On the other hand, when more than one barrier is placed between a roadway and a receiver, the combined effect is not to provide significantly greater attenuation than the single barrier. For design purposes, the general procedure is to assume the attenuation of the most effective barrier.

One implication of this is that when a barrier exists between the roadway and receiver, and it is desired to construct a second barrier to provide additional noise reduction, the attenuation provided by the first barrier is lost and only the attenuation of the second will be useful to reduce noise levels.

2-5 Ground Effects

Consider again the direct path of sound from the source to receiver as illustrated in Figure 2-1 in the absence of any obstacles. For sources and receivers located close to the ground, in addition to this direct path sound energy may reach the receiver by reflecting off the ground. When the terrain is relatively hard and flat, such a reflection will add to the noise from the direct path to increase the level at the receiver. However, when the ground is soft, there may be a phase reversal upon reflection such that the noise from the ground reflection path will destructively interfere with the noise from the direct path resulting in a reduction in level at the receiver which could be quite significant.

This reduction in level, known as ground-effect attenuation, is in excess of the 3 dB per doubling of distance propagation loss for a line source of noise and occurs only above soft absorptive ground (such as normal earth and most ground with vegetation). Over hard ground (such as concrete, stone and very hard-packed earth) these ground effects do not occur. These effects are most apparent for receivers on the ground floor, and decrease rapidly as receiver height above ground increases.

While ground absorption effects are not completely understood, it is generally believed that these effects account for the 4.5 dB per doubling of distance propagation loss observed over soft ground, as compared to the 3 dB propagation loss observed over hard ground. The implication with regard to barrier design is that placement of a barrier over soft ground between source and receiver will re-direct the sound over the top of the barrier, thus destroying the ground reflection and the additional 1.5 dB per doubling of distance attenuation. Thus, the barrier must be designed to provide more reduction than would otherwise be necessary, to compensate for the lost ground effects over absorptive ground.

2-6 Barrier Insertion Loss

The noise level observed at a particular location after construction of a noise barrier will depend on all of the factors discussed above. It is useful to define the concept of barrier insertion loss (IL) as the difference in noise level measured at a receiver location before and after construction of the barrier.

This insertion loss is a function of the following:

$$IL = f\left(\Delta_B, TL, \Delta BAR, \Delta_S, \Delta_G\right) \tag{2-2}$$

where

Δ_B = barrier attenuation resulting from diffraction over the barrier top

TL = transmission loss through the barrier

ΔBAR = change in barrier attenuation resulting from multiple reflections from double barriers

Δ_S = shielding attenuation from other barriers between highway and receiver

Δ_G = attenuation from ground effects

The barrier attenuation Δ_B, transmission loss TL, and change in barrier attenuation ΔBAR combine to give a net noise reduction, NR, for the barrier. That is,

$$NR = f\left(\Delta_B,\ TL,\ \Delta BAR\right) . \qquad (2\text{-}3)$$

Before construction of the barrier, the receiver may have been shielded by another barrier. Alternatively ground effects may have influenced the noise level at the receiver. (Typically both effects would not have occurred together, since the other barrier would have destroyed the ground effects.) Thus the insertion loss at the receiver due to construction of the barrier would be

$$IL = NR - \max\left(\Delta_S,\ \Delta_G\right) \qquad (2\text{-}4)$$

since the shielding due to the other barrier Δ_S or the ground effects losses Δ_G, if originally present, would be lost upon construction of the barrier. Note that the notation max(a,b) means that the larger value of a and b is to be used in the equation. Also note that Δ_S does not include the shielding provided by rows of houses or vegetation.

It should be clear from the above equation and discussion that determination of the effects of a noise barrier solely on the basis of diffraction over the top of the barrier will not provide a true picture of the net benefit of the barrier.

CHAPTER 3
BARRIER DESIGN CONSIDERATIONS

The previous chapter addressed the basic physical principles underlying barrier noise reduction. In this chapter, these basic concepts are applied to the design process to give the highway designer an understanding of the various factors that must be considered to build a barrier that is acoustically effective; i.e., a barrier which provides the required insertion loss without being "overdesigned." This chapter also provides information about the factors to be considered in barrier design that are related to non-acoustical features of barriers, such as maintenance, aesthetics, safety, construction, and costs. Also considered in this chapter is the role of community participation in barrier design.

Figure 3-1 shows a flow chart of the major elements of the barrier design process. As shown on the figure, the noise reduction goals influence the acoustical considerations, which in conjunction with the non-acoustical considerations determine various barrier design options. These options are then evaluated and a single design is selected, optimized and implemented. Input from the community is incorporated throughout the process.

For reference, the numbers in italics in each box correspond to the section in this chapter which addresses the particular subject indicated. The encircled numbers refer to the appropriate steps in the barrier design procedure in Chapter 4.

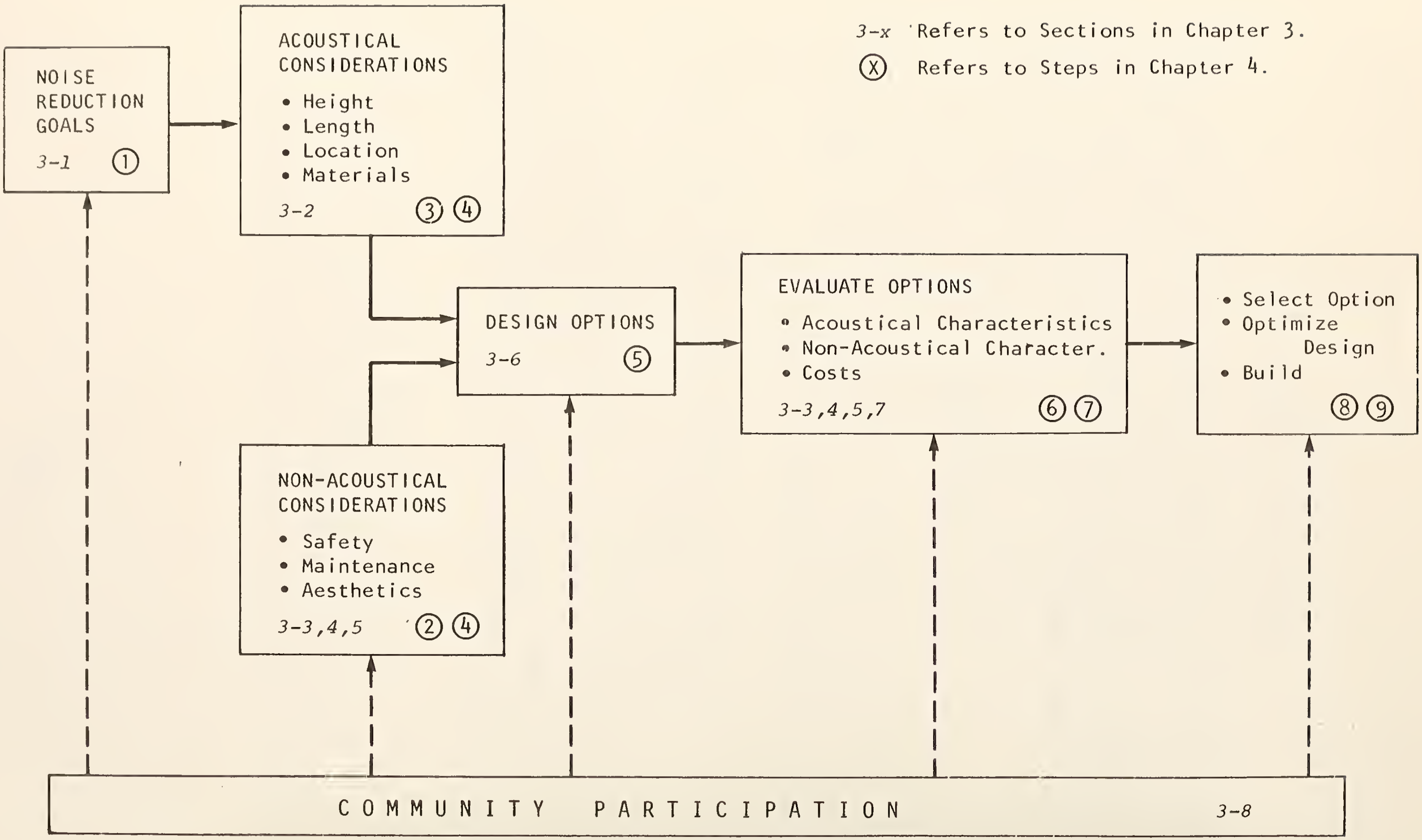


FIGURE 3-1 Barrier Design Process Flow Chart.

Much of the material presented in this chapter thus provides background and rationale for this design procedure. In applying the procedure in Chapter 4, then, knowledge of the considerations discussed in this chapter will be invaluable.

3-1 Design Goals

As a starting point in the design process, design goals should be set. These may take the form of a desired uniform reduction of X dB for a particular community, or, more likely, individual receiver levels would be defined and a desired criterion level selected. The design goal insertion loss would then be the difference between the present level and the criterion level for each receiver (selection of "critical receivers" will be discussed below; these are receivers picked so that when the design goals are achieved for their location, they are achieved for the entire community of interest.) Although this design goal may be modified during the course of the design process, it is extremely useful to identify early a target for which to aim.

As discussed in Chapter 2, the insertion loss provided by a barrier depends upon the diffraction of sound over the top and flanking around the sides of the barrier, transmission of sound through the barrier, multiple reflections caused by double barriers, and the potential loss of ground effect attenuation or the attenuation of other shielding elements between the roadway and receiver. The design goal insertion loss may then be expressed as follows:

$$\text{Design goal IL} = L(\text{before}) - L(\text{criterion})$$

$$= NR - \max\left(\Delta_S, \Delta_G\right) \qquad (3\text{-}1)$$

where

$$NR = f\left(\Delta_B, TL, \Delta BAR\right) \qquad (3\text{-}2)$$

In this equation L(before) and L(criterion) are expressed as either L_{10} or L_{eq} levels in dBA. The noise reduction NR is the net barrier benefit resulting from diffraction, transmission, and double barrier effects. In order to achieve the desired insertion loss, the barrier must therefore be designed to achieve a design goal noise reduction defined as follows:

$$\text{Design goal NR} = L(\text{before}) - L(\text{criterion}) + \max\left(\Delta_S, \Delta_G\right) \qquad (3\text{-}3)$$

With proper selection of barrier material and construction techniques, transmission through the barrier should not significantly compromise barrier performance. Further, if parallel barriers are not to be constructed, then the design goal NR will effectively become the design goal for the barrier attenuation Δ_B.

In order to determine the various parameters in the above equation, the highway designer may use one of the methods available, that is 117/144 or TSC. Alternatively, for existing highways, some of these parameters may be determined by actual field measurements at particular locations of interest. As an added benefit, use of field measurements to determine L(before) provides useful documentation of pre-barrier conditions, and can be used to validate the analytical predictions.

Even if analytical methods alone are used to determine noise levels for the "before" case, use of field measurements to determine possible ground absorption effects, Δ_G, would be most useful. Such measurements would involve measurement at a typical ground level receiver location (5 feet above ground), with simultaneous measurements at least 20 to 25 feet in the air; the difference in level between these two measurements is a good measure of the amount of absorption caused by ground effects. Note that when field data defining Δ_G are not available, the design curve provided in Chapter 4 may be used. This curve is based on a 1.5 dB per doubling of distance (from 50 feet) increase, to an arbitrary maximum of 5 dBA.

Since the attenuation provided by a barrier is critically dependent upon the height of the noise source, the design goal attenuation for the barrier must be translated into a design goal attenuation for sources at different heights. Usually, highway noise sources may be grouped into two height categories: ground- or zero-foot sources, resulting from automobile and light and medium truck tire noise; and eight-foot sources, resulting from heavy truck engine and exhaust noise. Although not technically correct, for convenience in the remainder of this handbook all zero-foot sources will be called cars, and all eight-foot sources will be called trucks. In Chapter 4, the attenuation provided by a barrier for car and truck sources relative to the total attenuation of the barrier is defined as a function of the relative car and truck contributions to the total traffic noise environment. From this information the design goal attenuations for cars and trucks may be determined from the design goal attenuation for the total traffic flow.

Any barrier which breaks the line of sight between the source and receiver will generally provide 5 dBA attenuation. However, because of possible loss of ground attenuation, the insertion loss of such a barrier is often only 1 or 2 dBA. Further, even if a full 5 dB is obtained, this magnitude of noise reduction subjectively does not usually appear to be very significant. Thus the wisdom of building a barrier to achieve an attenuation of 5 dB should be carefully considered.

It is usually quite possible to achieve a 10 dB barrier attenuation using walls or berms of reasonable height and length. An attenuation of 15 dB is more difficult to attain, and usually involves fairly high structures, the use of materials with high transmission loss characteristics, and attention to details of construction to ensure that leaks or openings are minimal. The length of such a barrier is usually significant.

To achieve a 20 dBA noise reduction is nearly impossible. For the purposes of this handbook, a 20 dBA limit has been placed on the attenuation provided from any barrier. If the design goal insertion loss exceeds 20 dB (or is much greater than 15, for that matter), the highway designer should seriously consider the use of other noise reduction measures to achieve the desired noise environment, or use of a barrier to partially reduce highway noise levels supplemented with other measures to jointly achieve desired levels.

As a summary of the magnitude of reduction achievable with noise barriers, Figure 3-2 categorizes barrier attenuation in 5 dB steps. For comparison purposes, the figure also indicates the actual reduction in acoustic energy, and the corresponding subjective assessment of this reduction, for each attenuation step. Note that a 10 dB reduction in noise level is necessary to reduce the loudness by half, even though this corresponds to elimination of 90% of the acoustic energy. As can be inferred from the figure, small differences in attenuation would not evoke significantly different subjective reactions.

While developing barrier designs to meet design goals, the designer will find it a fairly simple matter to evaluate the noise reduction benefits, as well as costs, of increasing barrier height and/or length. It may be appropriate therefore, depending upon cost tradeoffs, to build slightly better barriers if the extra cost involved is not significant.

On the other hand, use of other measures to reduce noise exposure may turn out to be less costly than construction of a barrier of sufficient height and length to meet design goals, depending upon specific circumstances and highway-community configurations. Thus, application of these other measures should not be eliminated from consideration until after the highway designer has gone through the procedure of Chapter 4 and determined the cost of the noise barrier selected.

The important point here is that although a design goal insertion loss is chosen at the start of the design process, it may be increased if found to be cost-effective, or

FIGURE 3-2

BARRIER NOISE REDUCTION RELATIONSHIPS

Barrier Noise Reduction	Level of Feasibility	Reduction in Acoustic Energy	Reduction in Loudness
5 dB	Simple	68%	30%
10 dB	Attainable	90%	50%
15 dB	Very Difficult	97%	65%
20 dB	Nearly Impossible	99%	75%

decreased (or the barrier eliminated entirely), if other measures are shown to be more cost-effective. Thus the highway designer should remain flexible in his approach so that all options are pursued and analyzed.

A final point is in order. Just as it was important to obtain measurements at important receiver locations before construction of the barrier to document existing levels, it is quite useful to make measurements after barrier construction to document actual barrier performance. Such measurements will provide a true measure of the insertion loss of the barrier. If the barrier has met its design goal, these measurements are useful from a community relations point of view. If the design has not been successful, it is important to recognize that fact so that, if possible, the problem can be remedied. Even if it is not possible to remedy the problem, analysis of the reasons that the barrier does not achieve its design insertion loss would provide a useful lesson which could be of great benefit in the design of future barriers.

3-2 Acoustical Considerations

As discussed in Chapter 2, the attenuation of a barrier is directly related to the path length difference δ of the diffracted sound over the top of the barrier as compared with the direct path from the source to receiver in the absence of the barrier. This assumes that the barrier is infinitely long, parallel to the roadway, and of constant height. How do these concepts translate themselves to the real world, and influence the practical design of a barrier?

Consider first the parameters of barrier height and location relative to the roadway. At a fixed distance from the roadway, increasing the height of the barrier will increase its attenuation characteristics. This relationship is non-linear, however; for low values of attenuation, increasing the wall height a constant amount may provide reasonable increases in attenuation. For this situation, it would be very cost-effective to increase wall height, because the attenuation per foot of height is large. Once the attenuation has increased substantially, however, increasing the height of the wall may provide very little additional benefit in terms of increasing attenuation. In this region increasing the height of the wall the same amount will provide much less benefit. This situation is illustrated in Figure 3-3. Note however that despite this non-linear behavior, for rough approximation purposes a value of 1/2-dB attenuation per incremental foot of height may be used to estimate the approximate height of a wall to achieve a desired attenuation, assuming that a wall which just breaks line-of-sight provides 5 dB attenuation.

For a constant barrier height, moving the wall close to the receiver, or close to the source, provides increasing attenuation. However, in practical design, it may be possible to take advantage of local terrain conditions to find a barrier location which can benefit from higher elevations. This situation is illustrated in Figure 3-4 in which a short barrier wall placed on a hilly terrain combines to provide more attenuation than a higher (and therefore more expensive) wall located closer to the roadway.

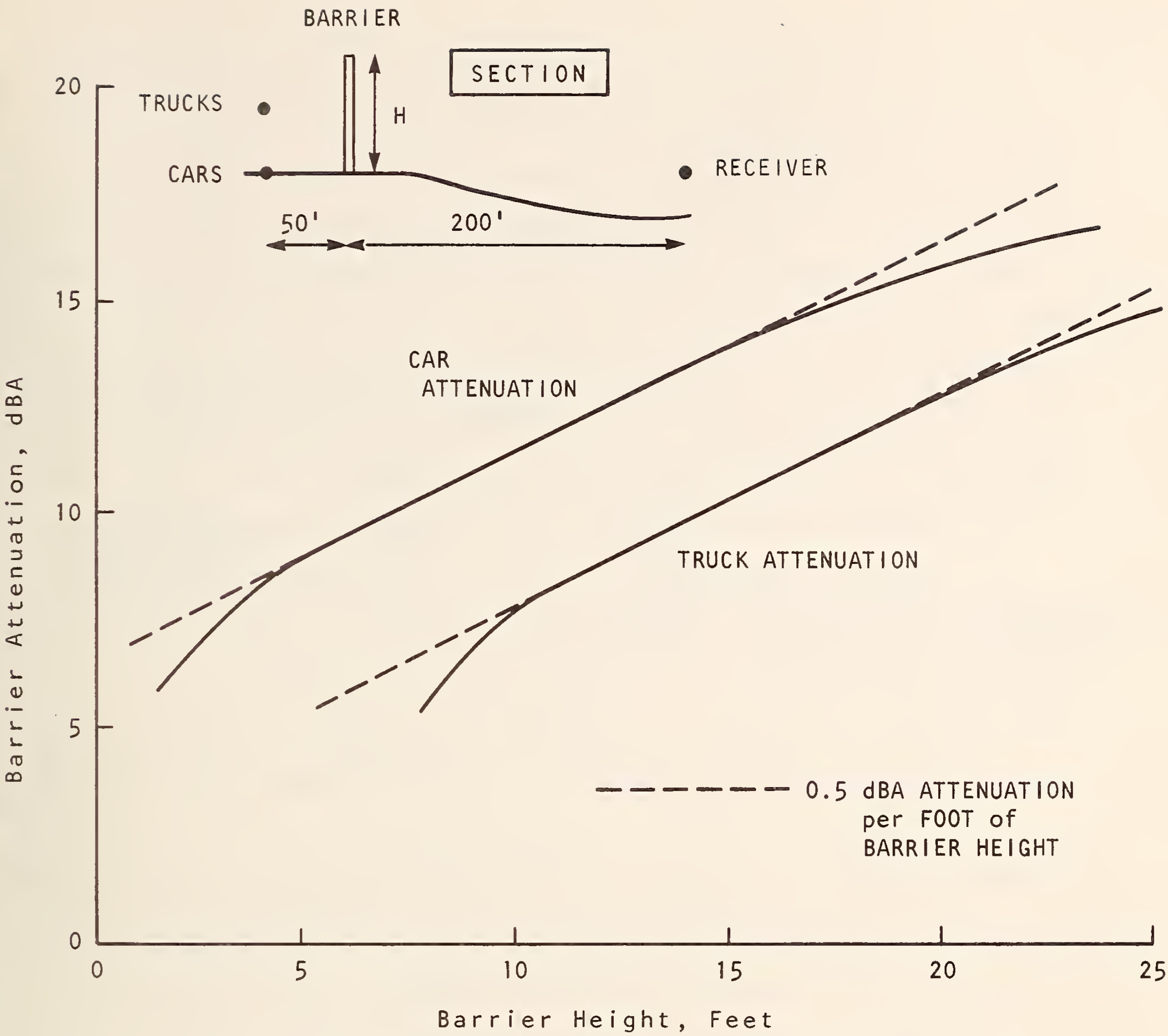


FIGURE 3-3 Barrier Attenuation as a Function of Barrier Height.

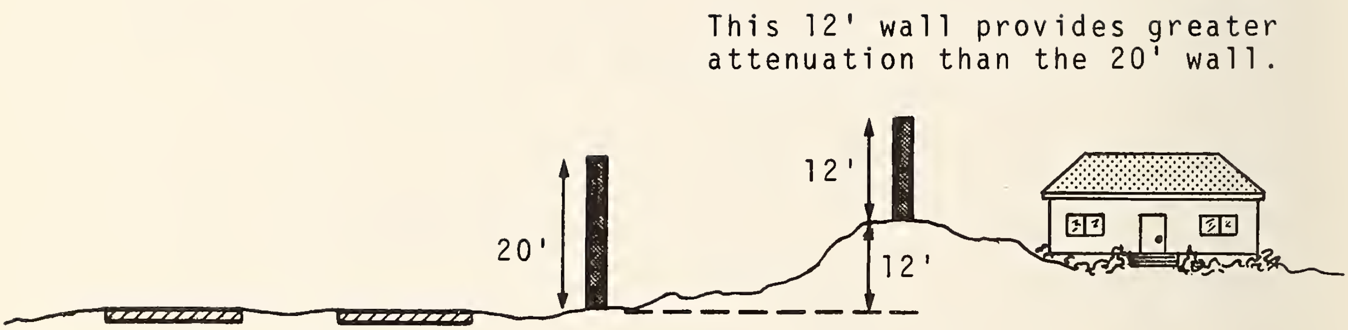
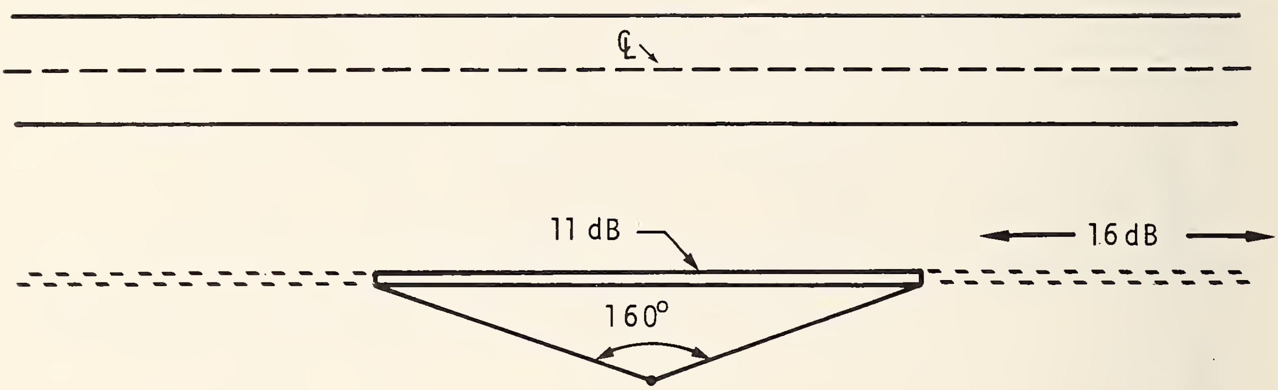


FIGURE 3-4 Use of Elevated Terrain to Achieve Greater Attenuation with Lower Walls.

In practice, one does not build infinite barriers. Yet the need for barriers which subtend large angles from observers is a real one. Consider the situation illustrated in Figure 3-5 in which a barrier of "infinite" length, with a subtended angle of 180°, would provide an attenuation of 16 dB. The same barrier subtending an angle of 160° will provide only 11 dB attenuation. Note that for a receiver 500 feet from the roadway, a barrier which subtends an angle of 160° would be more than a mile long; still, this barrier has been degraded by 5 dB because it is too short. How can this situation be remedied? There are basically two ways. One is to take advantage of natural terrain conditions and the presence of structures to provide the necessary "infinite" length, as shown in Figure 3-6. The other method, which may have to be used if terrain and structures do not provide the necessary shielding at the end of the barrier, is to bend the barrier back toward the community to achieve a larger subtended angle through much reduced length, as shown in Figure 3-7.

Until now, the discussion has been directed toward the height, location, and length considerations necessary to achieve a desired insertion loss for one particular receiver. In the typical situation, however, there may be many receivers for whom the barrier is being designed to protect. These are receivers who are or will be exposed to noise levels higher than criterion levels, as determined by field measurements or analytical procedures (resulting perhaps in noise exposure contours). Since it clearly is impractical to evaluate the various design options for every receiver of interest, it is useful to identify a few "critical receivers" for whom selection of proper barrier parameters is most crucial. Conceptually, these receivers would be picked so that a barrier



160° barrier provides 11dB attenuation.

"Infinite" barrier provides 16 dB attenuation.

FIGURE 3-5 Illustration of Loss of Attenuation with Short Barriers.

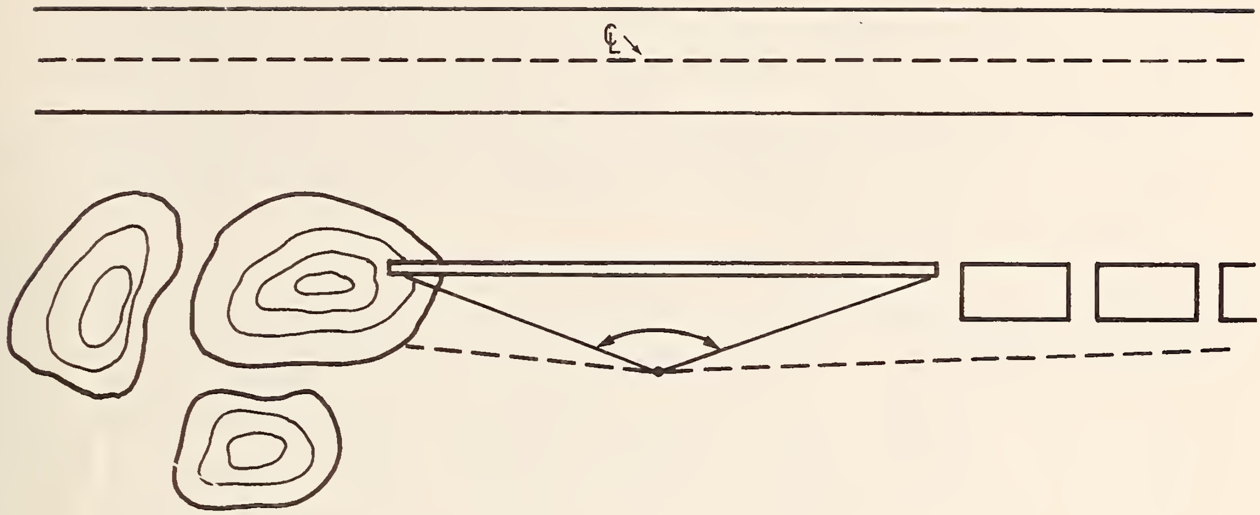


FIGURE 3-6 Use of Local Features to Achieve an "Infinite" Barrier.

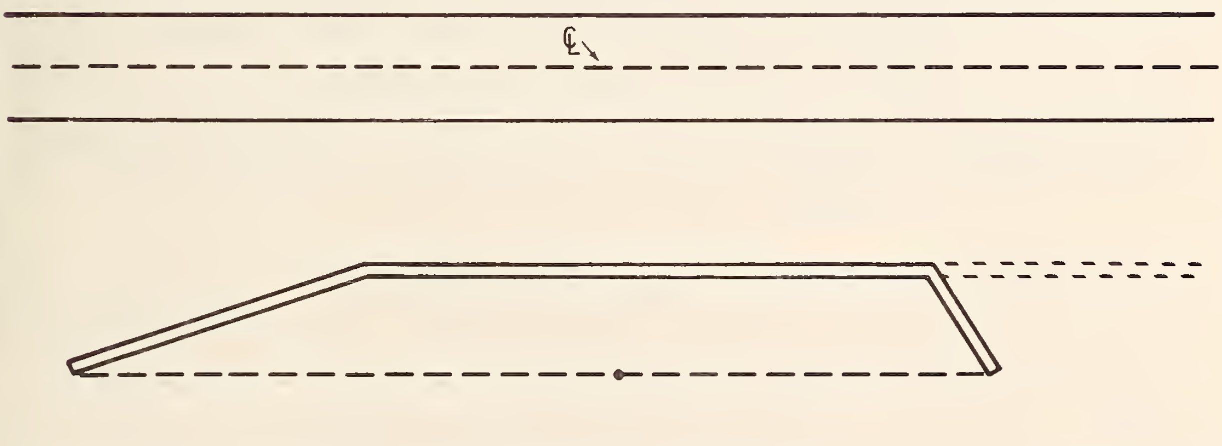


FIGURE 3-7 Use of Short Segments Wrapped Around the Receiver to Achieve an "Infinite" Barrier.

design which achieves the desired noise reduction goals for these receivers would also meet or exceed desired goals for all other receivers of interest. Clearly, the smaller the number of critical receivers necessary to satisfy these requirements the better.

Explicit guidelines cannot be given for the selection of critical receivers. Typically, however, the highest noise levels and therefore the greatest noise reduction requirements will apply to the closest receivers. Selection of barrier location and height will then be dictated by the noise reduction requirements of these receivers. Usually the noise level will drop off with distance from the highway at a faster rate than the decrease in barrier attenuation with distance from the barrier. Thus, if the noise level at the closest receiver is reduced to design levels, the noise level at the farthest receiver of interest will also be within desired limits. However, if the barrier protecting the close-in receiver is significantly less than infinite, the length of barrier required to protect the close-in receiver may be insufficient for the farthest out receiver. Thus the close-in receiver may determine the barrier height while the far-out receiver may determine its length.

Of course there rarely is the situation of a single column of receivers extending out from the roadway. The considerations described above must be extrapolated to an entire community area. Consider the simplified situation shown in Figure 3-8. It is the receivers on the right of the community who will determine the height and length requirements for the barrier in that vicinity extending to the right, while the receivers on the left will control the barrier dimensions for the left

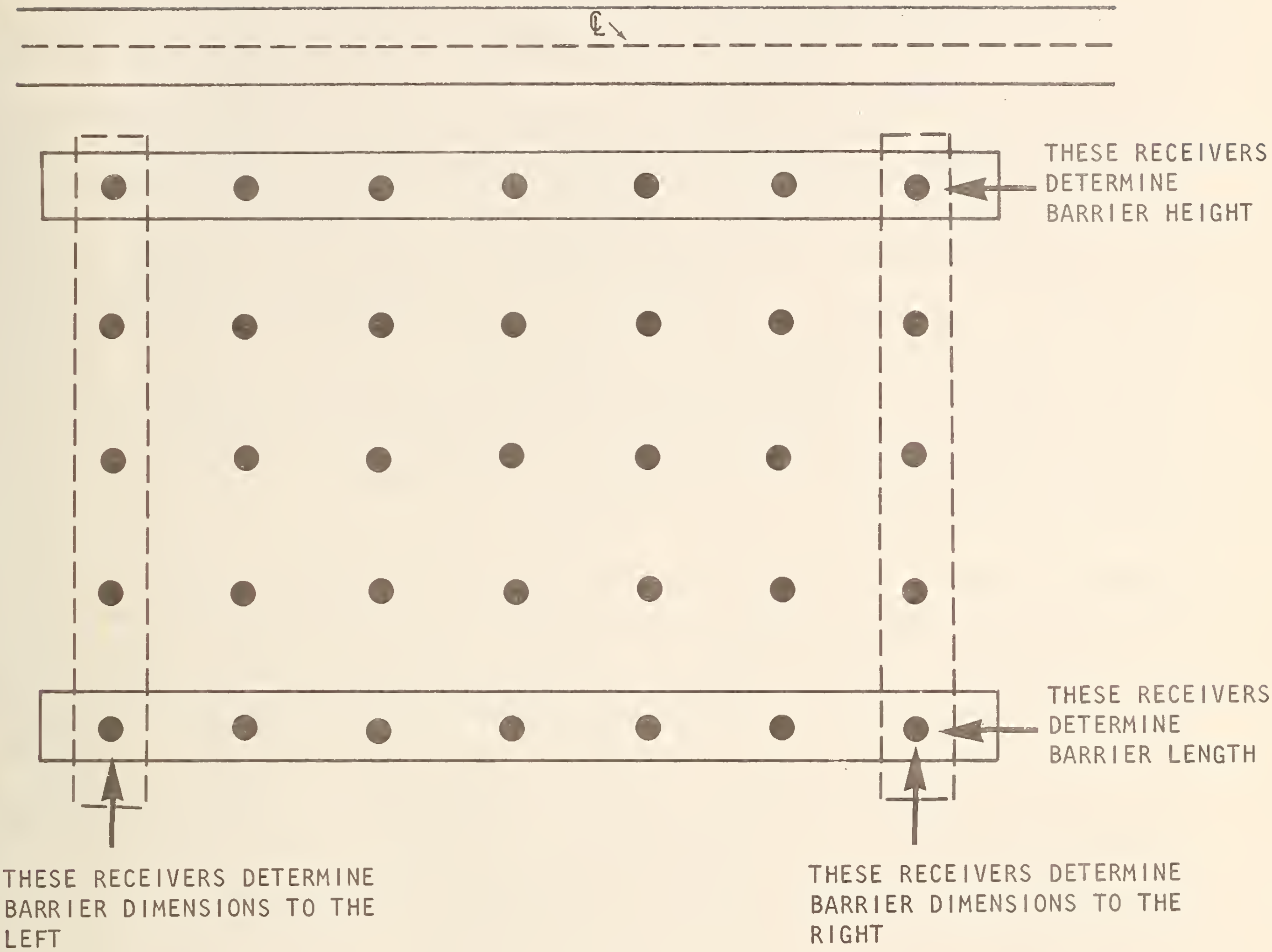


FIGURE 3-8 Critical Receiver Considerations.

portion of the barrier. Note that there is no requirement that a barrier have constant height throughout its entire length. The necessary height will vary according to the location and height of the various receivers, as well as changes in alignment, grade, and cross-section configuration of the highway. When a community extends for a considerable distance along the highway, it may be appropriate to divide the route into sections, and effectively design separate barriers for each section, with different heights along each. Knowledge of the highway alignment and elevation will provide guidance as to whether adjoining sections of receivers will achieve sufficient benefit from the section of barrier upstream or downstream, which might be lower than the height of the barrier immediately between them and the roadway.

Because of these complexities in highway and community configurations, as well as variations in terrain features, it is often advisable to make use of available computer programs (such as TSC) to properly evaluate the effects of these various factors so that the attenuation provided by a barrier of varying height can be determined for an array of observers. Of course, such a procedure could become very time consuming and costly if many different barrier design options are evaluated in this manner. Alternatively, a uniform height barrier may be used along all sections of the road, with simplifying assumptions made about the highway-community configuration. For purposes of comparing the costs and non-acoustical characteristics of different barrier designs, use of single height barriers is certainly adequate. After a specific design is chosen, it can be refined and optimized by computer into different height sections. This approach will be discussed in greater detail in Chapter 4.

As indicated in Chapter 2, the performance of a barrier can be seriously limited by transmission through the barrier and by reflected sound energy due to the presence of a second barrier on the other side of the highway. Selection of barrier material with sufficiently high transmission loss characteristics in terms of both the material itself and the absence of holes or openings in the material is quite important. Similarly selection of sound absorptive material treatments for barrier application also deserves serious consideration.

Another way that barrier performance can be compromised is the presence of large gaps or discontinuities in the design to accommodate pedestrian access, cross-street penetration, or access to the roadway for maintenance purposes. Wherever possible, the effects of these gaps should be minimized by overlapping sections of barrier, providing a tight-fitting access door, or bending back the barrier ends toward the community to shield nearby receivers.

Conversely, it is possible to "overdesign" a noise barrier. For situations in which the design goal is not large (under 10 dB for example), selection of material with unnecessarily high transmission loss properties and meeting unnecessarily rigid specifications concerning openings may place a high price tag on the barrier that is unwarranted.

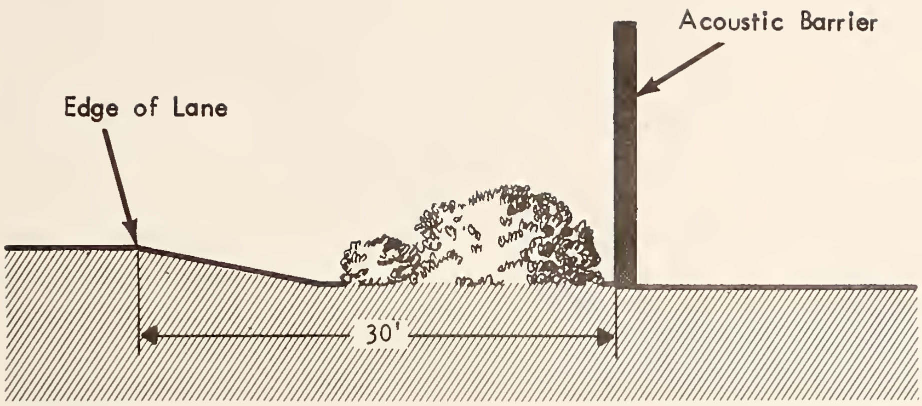
Serious overprediction of "before" noise levels at critical receivers would also result in an overdesigned noise barrier. One reason that this might occur is the failure to categorize traffic flow into automobiles, medium trucks and heavy trucks.

Use of only two categories (i.e., including medium trucks with heavy trucks) would often overpredict the noise level. Because of the different pecularities inherent in each of the analytical prediction methodologies that may be used, it is strongly recommended that the highway designer have a clear understanding of the strengths and weaknesses of the particular methodology he is using so that he knows how much faith to place in the estimated noise levels at receivers.

3-3 Safety Considerations

A number of safety factors must be considered when designing noise barriers. Clearly, a barrier should not be installed where it will present a hazard to safety.

From a safety standpoint, it is desirable to locate a noise barrier beyond the recovery zone from the traveled way. Where a roadside obstacle such as a noise barrier is within thirty feet of the traveled way, a traffic barrier may be warranted (Reference 3-1). However, it is recognized that this is frequently impractical in conditions where walls are added within an existing freeway right-of-way. In existing projects where desirable clearance may not be obtainable, such as on elevated structures, it is generally desirable to have a safety barrier used either in front of, or as part of the acoustical barrier. (See Figure 3-9.) In a crash situation, the vehicles tend to protrude over the top of the safety barrier, therefore the noise barrier wall may be subject to damage even with the inclusion of a crash barrier.



WHERE AN ACOUSTIC BARRIER IS WITHIN THIRTY FEET OF THE TRAVELED WAY, A TRAFFIC BARRIER MAY BE WARRANTED

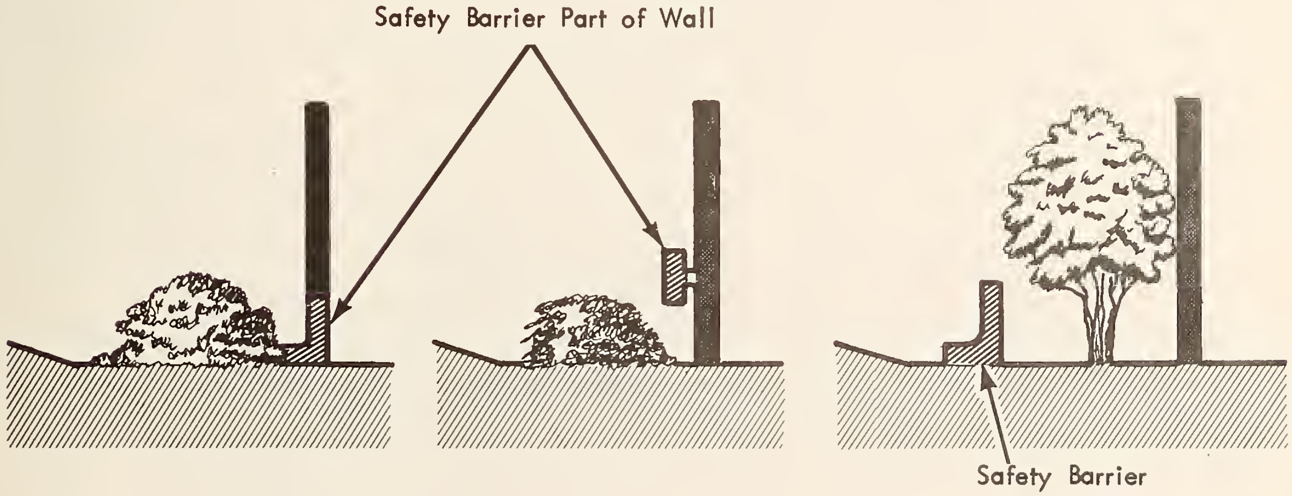
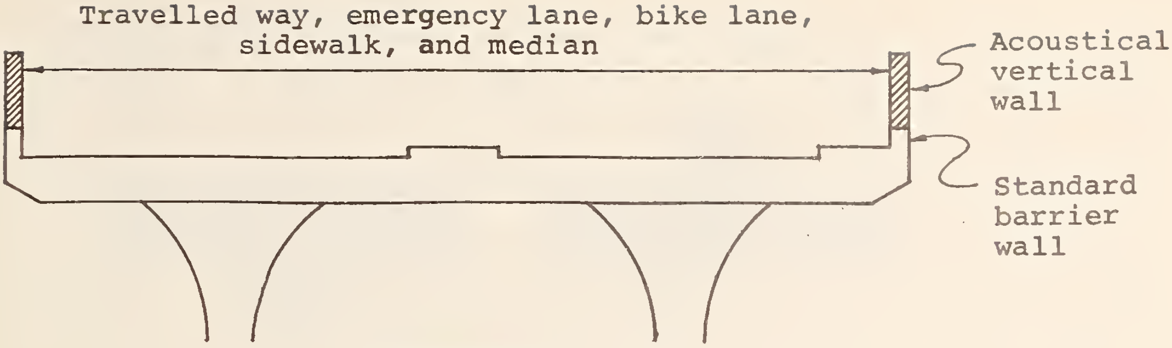


FIGURE 3-9. USE OF SAFETY BARRIERS

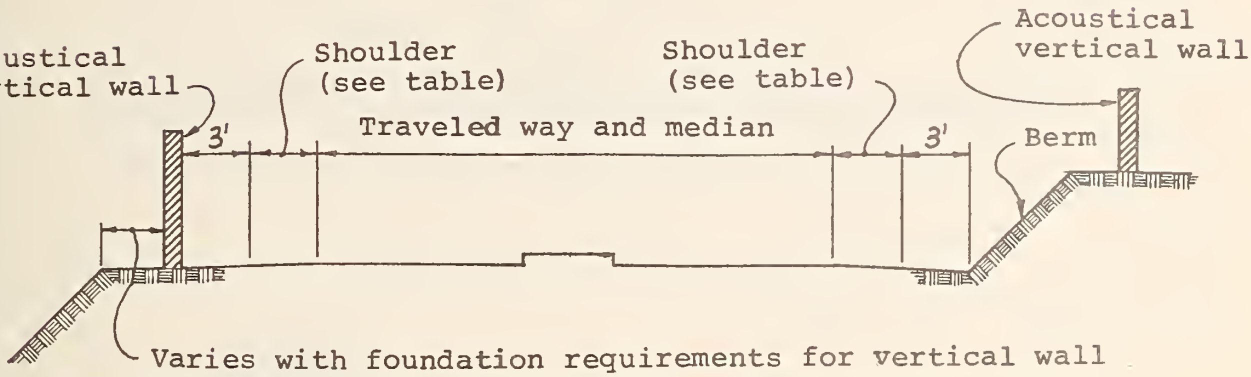
In general, the location of a noise barrier with respect to the traveled way will vary with the shoulder width required. As indicated in Figure 3-10, the width of the shoulder will vary from eight feet to twelve feet, depending upon the roadway characteristics. (Note however that for elevated structures there should be a minimum of four feet from the edge of the traveled way for adequate shy distance.) The location of the walls shown in the figure are for general conditions; however, each installation should be evaluated for traffic safety with special emphasis on alignment and sight distance.

Consideration must be given to safety when locating noise barriers in the vicinity of on- and off-ramps, ramp intersections, and intersecting roadways. A noise barrier should not block the line-of-sight between the vehicle on the ramp and approaching vehicles on the major roadway. Several specific conditions are described in the following.

For on- and off-ramps the minimum set back of a noise barrier is based upon the stopping sight distance, which is a function of the design speed and radius of curvature of the ramp. For ramp intersections, proper barrier location is set by the sight distance corresponding to the time required for a stopped vehicle to execute a left-turn maneuver (approximately 7.5 seconds). For intersecting roadways, barrier placement is determined from stopping sight distance, which depends on driver reaction time and deceleration rate. Design charts are included in Chapter 4 to assess proper barrier locations for these conditions. (Note that barrier termination considerations are discussed below in Sections 3-4 and 3-5.)



STRUCTURE



Type of cross section	Paved shoulder width* - feet Right of traffic
FREEWAYS	
(a) 4 and 6 lanes	10
(b) 8 lanes or more	10
(c) Separate roadways	10
(d) Auxiliary lanes	10
(e) Freeway to freeway connections	10
(f) Ramps	8
ULTIMATE EXPRESSWAYS AND HIGHWAYS WITHOUT ACCESS CONTROL	
Standard 2-lane Highways	8
Multilane Divided Highways:	
(a) Narrow Median with continuous curbs	8
(b) 4 and 6 lanes	8
(c) 8 lanes	8
(d) Separate roadways	8

* 10-12 feet where snow storage required.

FIGURE 3-10 Barrier Location for General Conditions on Freeways, Expressways and Highways

Snow removal considerations become a safety factor when the melting snow forms ice on the roadway surface. In general, the common practice in snow areas is to design highways with a minimum shoulder of ten to twelve feet to allow for snow storage areas when snow cannot be readily pushed over to the side due to the placement of a noise barrier. In this situation, it will be necessary for the snow to be first plowed off the traveled lanes onto the wider shoulders and, following the storm, load the snow into transport vehicles. In this case it is important to remove the snow from the shoulder as soon as possible to minimize the possibility of melting snow blowing onto the roadway at night and freezing. The surface treatment of the barrier also has safety implications. Protrusions on a barrier near a traffic lane, and facings which can become missiles in a crash situation should be avoided. See Figure 3-11.

The previous discussion and illustrations regarding barrier safety are intended as general guidelines. Consult references 3-1, 3-2, and 3-3 and appropriate state design standards for applicable criteria.

3-4 Maintenance Considerations

Maintenance factors include maintenance of the noise barrier itself; maintenance associated with adjoining landscaping; replacement of materials damaged by impact; and cleaning the barrier.

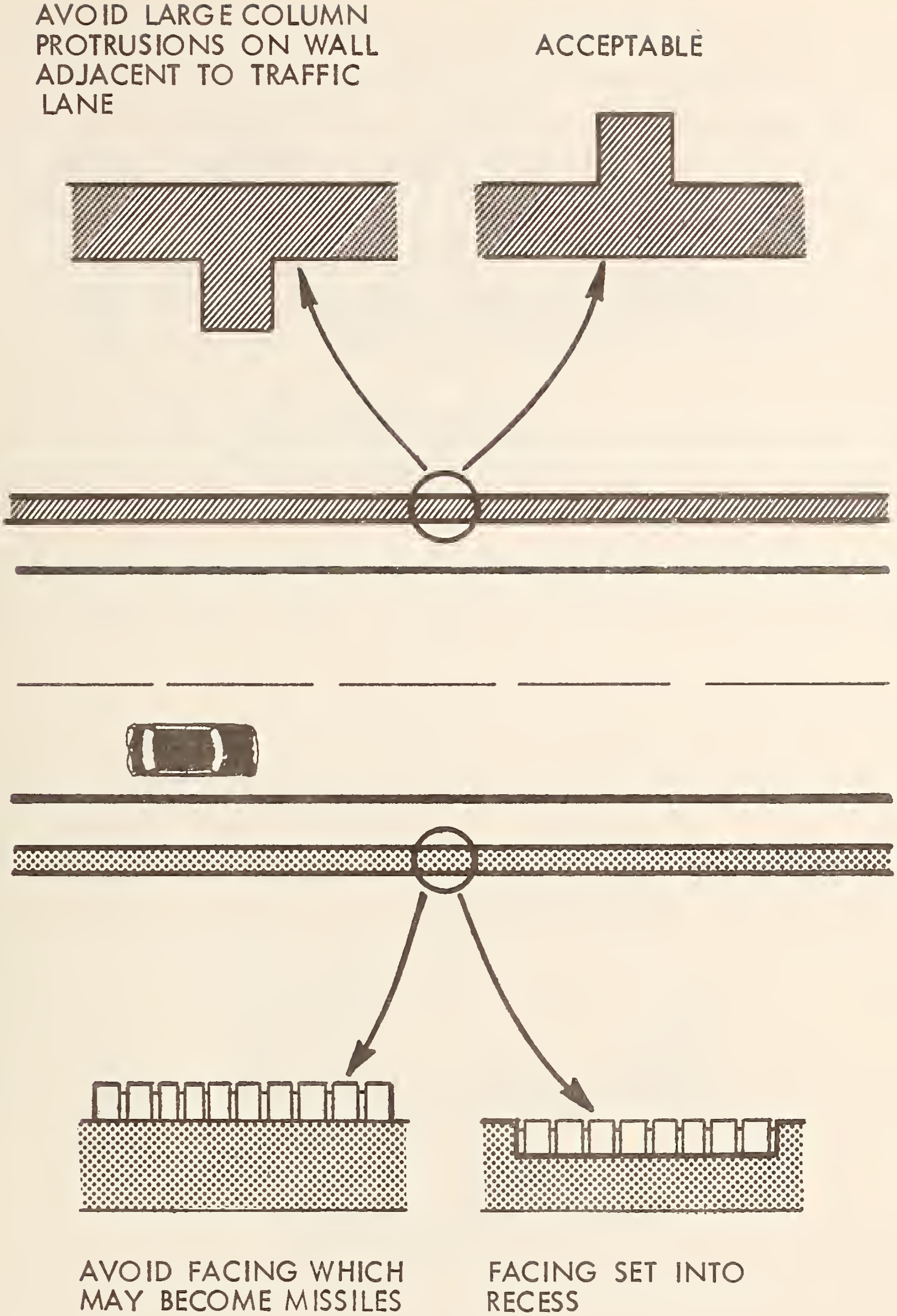


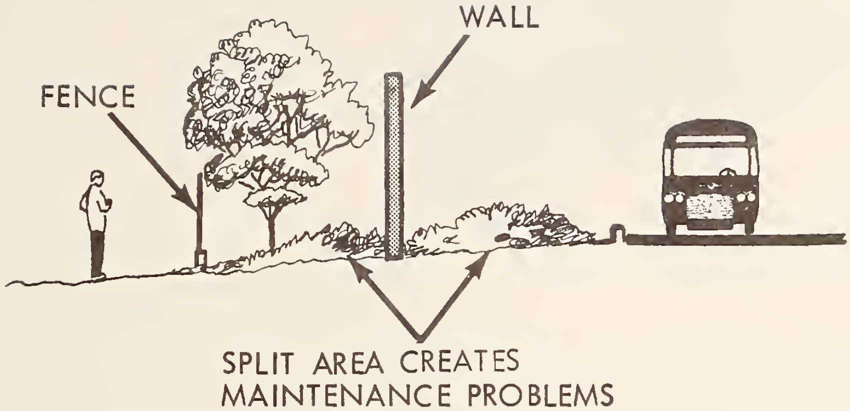
FIGURE 3-11. BARRIER DESIGN SAFETY CONSIDERATIONS

In general, maintenance of barrier materials is less costly if unpainted surfaces such as weathering steel, concrete, pressure-treated wood, or naturally weathered cedar or redwood are used. It is desirable from a visual and maintenance standpoint to use concrete surfaces which are left natural such as sandblasted finish and exposed aggregate, or with integral color, as opposed to painted surfaces which require continual long-term maintenance.

Maintenance of landscaping associated with the edge of the freeway right-of-way will be affected by both the wall placement and type of landscaping used. In general where the wall splits the area to be landscaped, it is desirable to utilize low maintenance landscaping on the far side (see Figure 3-12).

Providing access to the rear of the wall for maintenance purposes by varying the horizontal alignment of the barrier can also provide visual relief. (See Figure 3-13.) In general for both visual and safety considerations, the access breaks in the wall should be designed to avoid an abrupt wall facing the flow of traffic. Where a solid door is not provided for access, the overlap of the parallel barrier walls should be a minimum of twice the width of the opening and be treated with absorptive material, in order to maintain the acoustical effectiveness of the wall.

Another maintenance consideration with noise barriers is maintaining a stock of materials which are compatible with the barrier for replacement. This can be a serious problem, especially with naturally weathered finishes such as a pressure-treated wood.



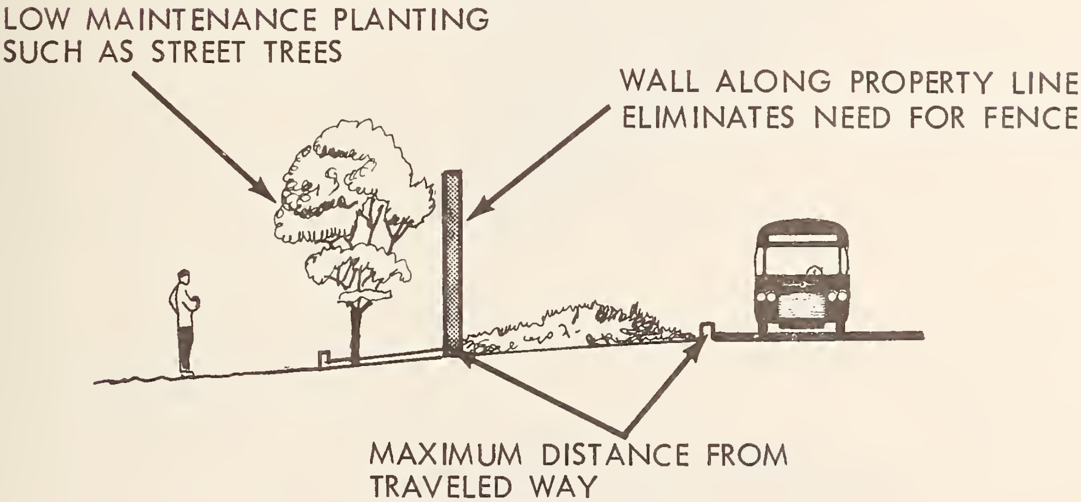
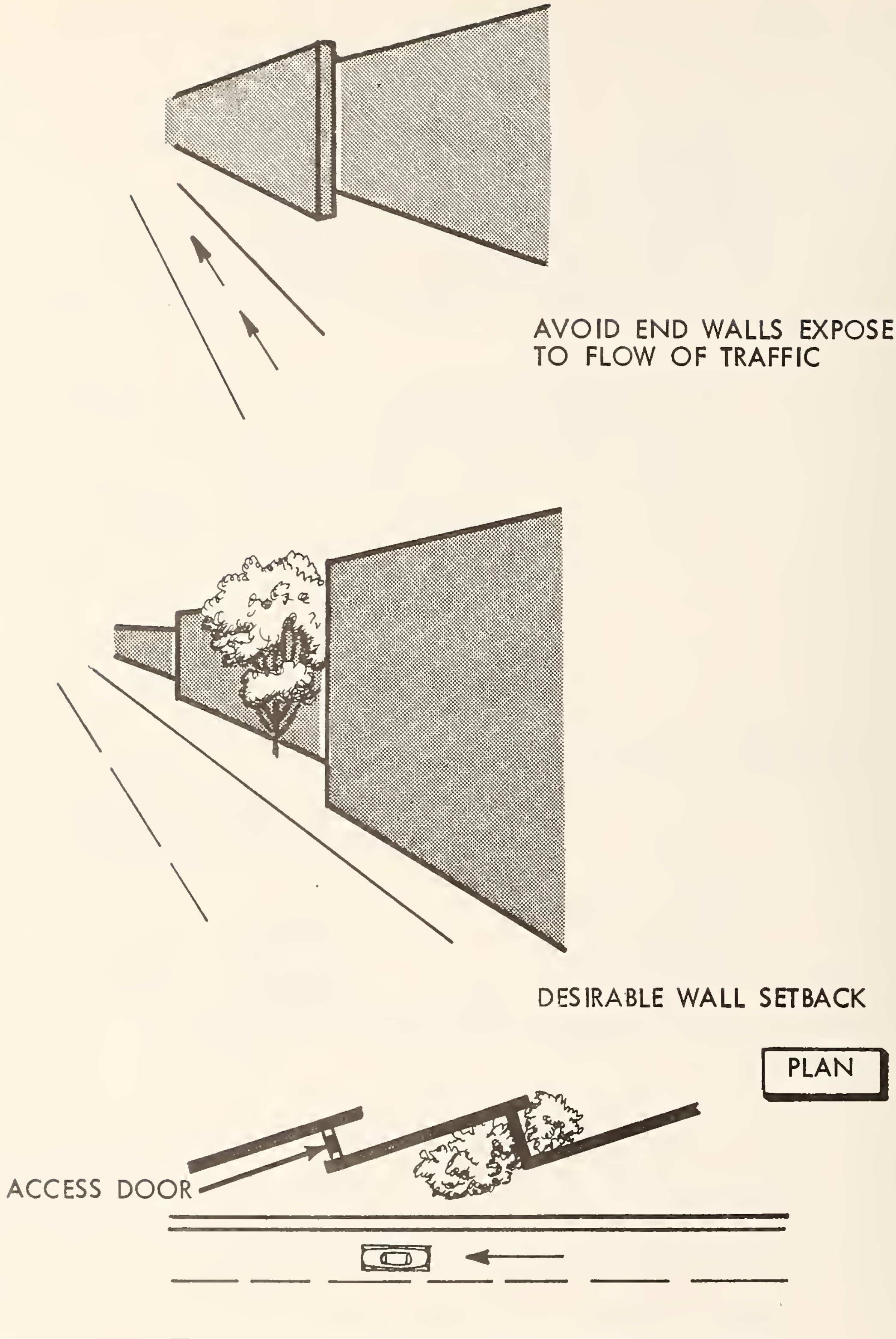


FIGURE 3-12. MAINTENANCE CONSIDERATIONS CONCERNING LANDSCAPING



GURE 3-13. PROVIDING ACCESS FOR BARRIER MAINTENANCE

Finally, snow removal may affect maintenance in the case of earth berms used as noise barriers. In this situation care should be taken to see that the planting materials used on the earth berm are resistant to the effects of salt and other chemicals which may be encountered in snow removal areas.

3-5 Aesthetics

A major consideration in the design of a noise barrier is the visual impact on the adjoining land use. Primary factors include scale relationship between the acoustic barrier and activities adjoining the highway right-of-way. Specifically, a high noise barrier adjoining a low-scale single family detached residential area could have a severe adverse visual effect. In addition, the high-scale wall placed close to residences creates adverse shadows and may affect the micro-climate. One solution to the problem of this scale relationship is to provide a stepped wall to reduce the visual impact through introduction of landscaping in the foreground; this allows additional sunlight and air movement in the residential area. In general, it is desirable for the wall to be located about four times its height from residences and landscaped to avoid being visually dominant (see Figure 3-14).

The visual character of noise barriers should be carefully considered in relationship to the environmental setting. In general, barrier concepts utilizing extensive landscaping are the most visually pleasing of any type of wall (see Figure 3-15 and 3-16). Walls should, as much as possible, and where desirable, reflect the character of their surroundings. Where strong significant architectural elements occur in close proximity to wall locations, a relationship of material, texture,

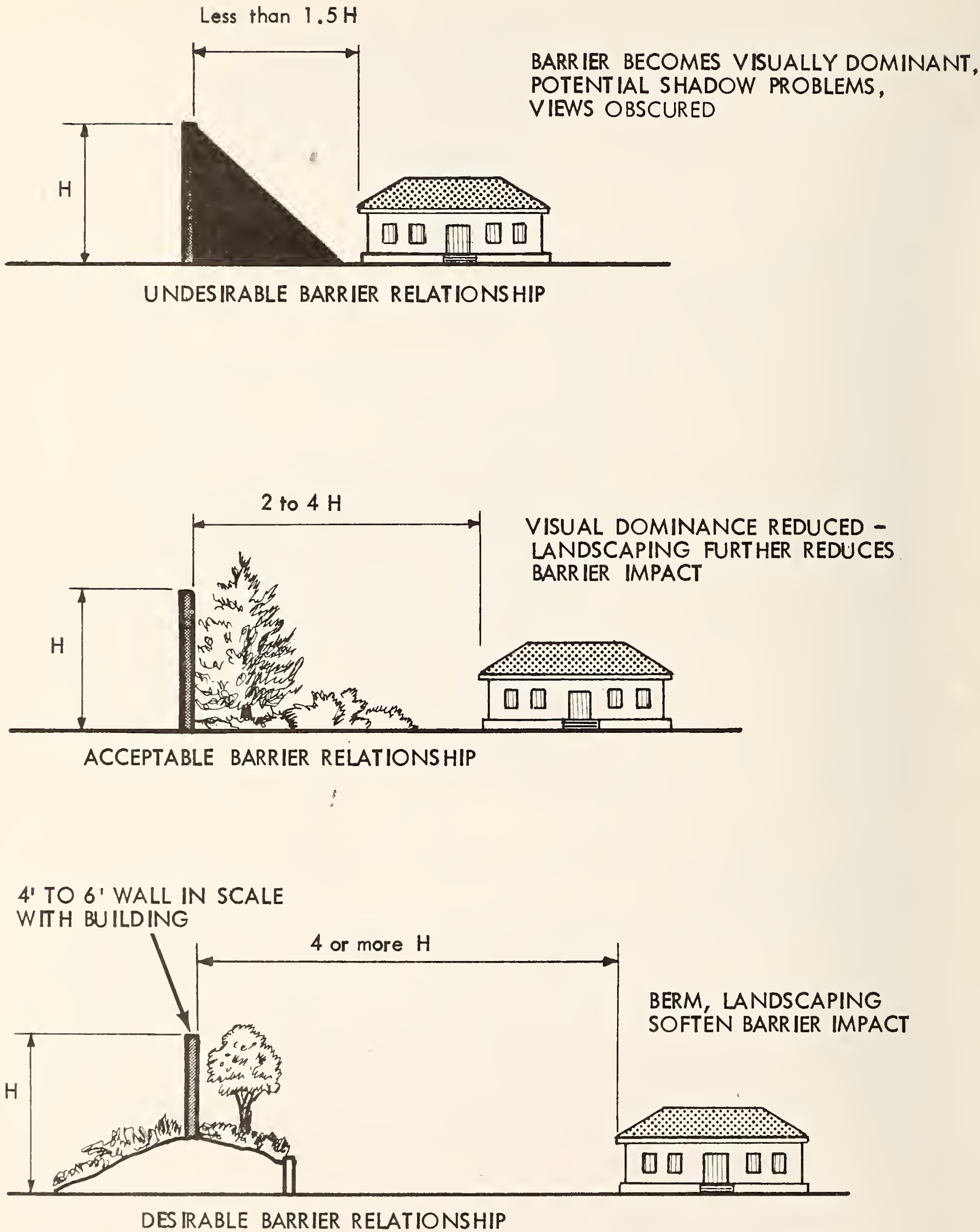


FIGURE 3-14. SPATIAL RELATIONSHIP OF BARRIER TO ADJOINING LAND USE

UNDESIRABLE

DESIRABLE

FIGURE 3-15. LANDSCAPING CAN BE VISUALLY PLEASING TO BOTH THE COMMUNITY AND THE DRIVER

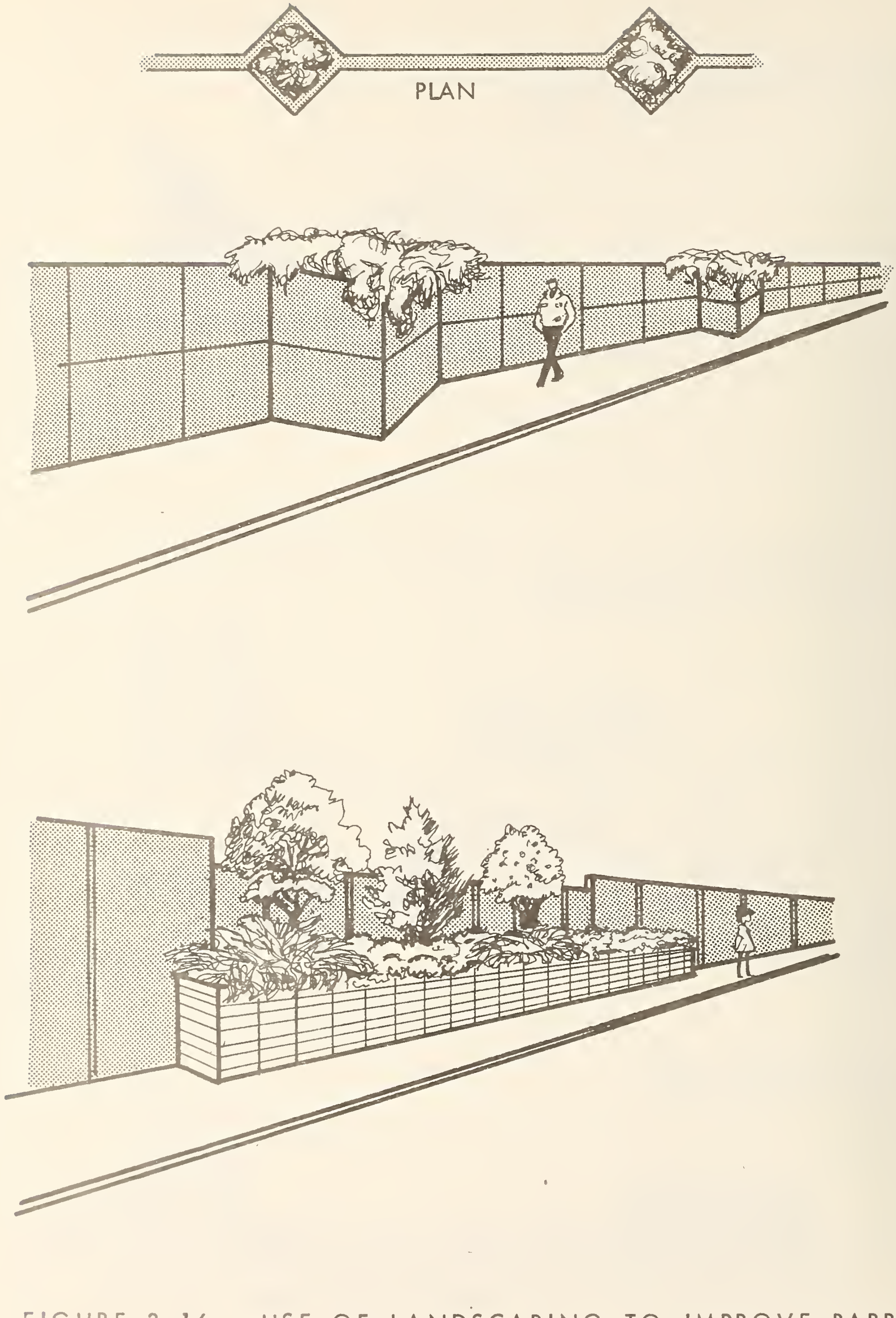


FIGURE 3-16. USE OF LANDSCAPING TO IMPROVE BARRIER APPEARANCE

and color should be explored, as shown in Figure 3-17. In other areas, particularly those closely related to freeway structures or other transportation elements, it becomes desirable that the barriers have a strong visual relationship, either physically or by design concept, to the highway elements. See Figure 3-18 for an example.

In general, a successful design approach to acoustical barrier walls is to utilize a consistant color and surface treatment with landscaping elements used to soften foreground views of the barrier. It is generally desirable to avoid excessive detail or a painted candystripe effect which tends to increase the visual dominance of the barrier (Figure 3-19).

Another important consideration is the impact of the noise barrier on the driver. At normal highway speeds, visual perception of noise barriers will tend to be of the overall form of the wall, its color, and texture. Due to the scale of acoustic barriers, the primary objective to achieve visually pleasing barriers will be to avoid a tunnel effect through major variations in form, wall type, and surface treatment. The most desirable visual treatment of noise barriers is generally through the use of landscaping material.

The design approach to noise barriers will vary considerably depending upon highway design constraints. For example, the design problem both from an acoustic and visual standpoint is substantially different for a straight highway alignment with narrow right-of-way and little change in vertical grades, than for a highway configuration which changes horizontal and vertical alignments and has a large right-of-way. In the former

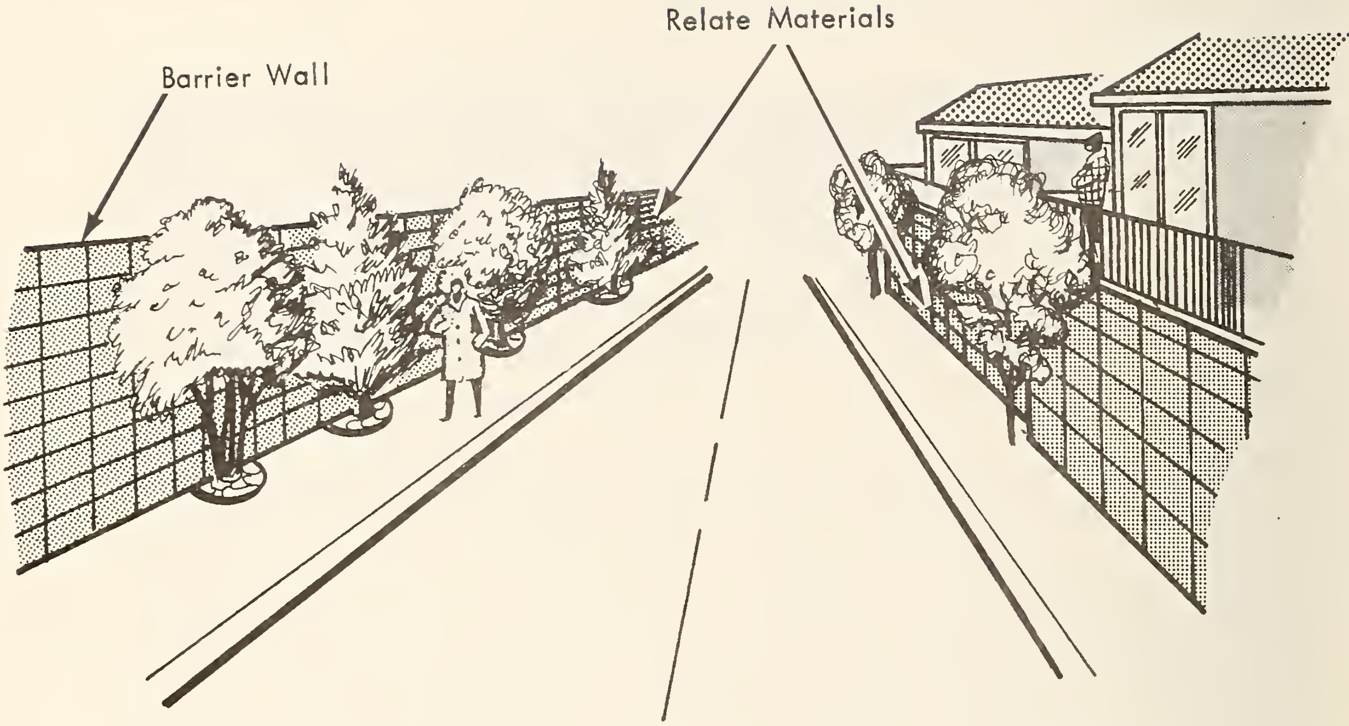


FIGURE 3-17. RELATING BARRIER DESIGN TO ARCHITECTURAL ELEMENTS IN THE COMMUNITY

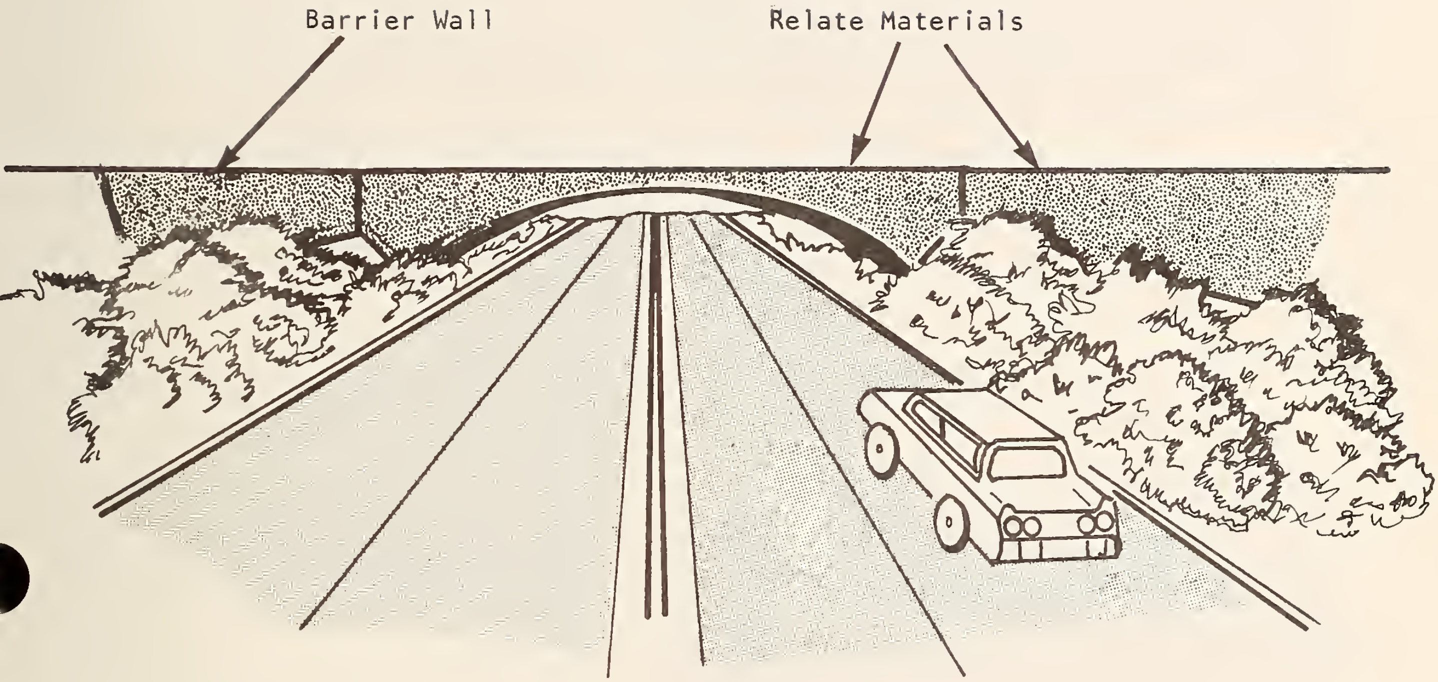
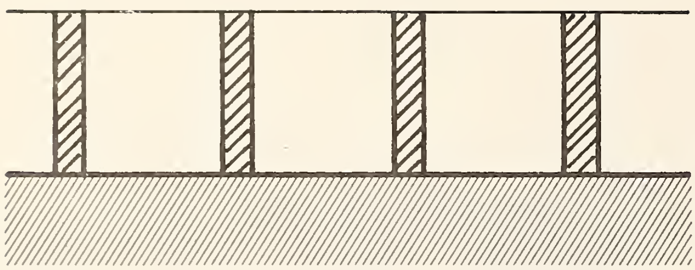
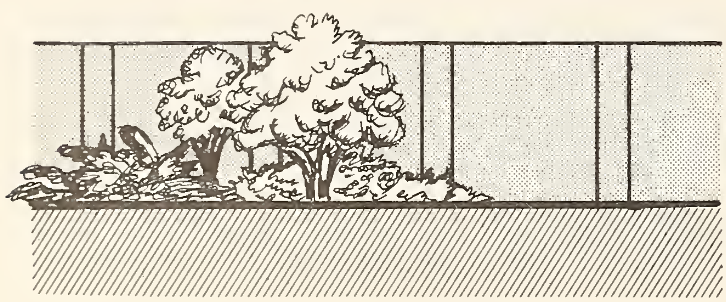


FIGURE 3-18. RELATING BARRIER DESIGN TO OTHER HIGHWAY ELEMENTS



AVOID CONTRASTING PAINTED "CANDYSTRIPE" EFFECT



USE SIMPLE TEXTURE AND LANDSCAPING TO SOFTEN WALL

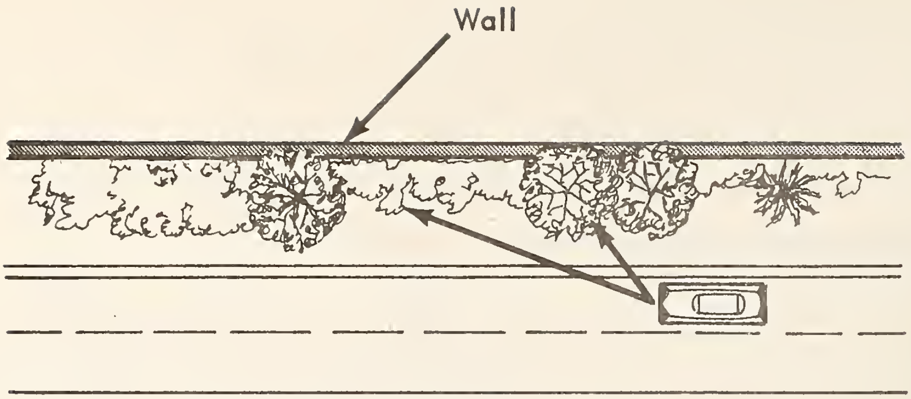
FIGURE 3-19. VISUAL CONSIDERATIONS IN BARRIER DESIGN case, the highway designer is limited in the options of visual design to minor variations in form, surface treatment, and landscape treatment. With a generous right-of-way adjoining the traveled way, the highway designer has the opportunity to vary wall type, utilize landscaped berming, and other approaches to develop a visually pleasing acoustic barrier.

One of the most positive approaches that the highway designer can take to improve the visual appearance of the barrier is by varying the forms and types of barrier wall along the length of the highway. Due to the high speeds traveled and associated perception, it is necessary for the highway designer to work with relatively major changes in visual form to significantly improve the appearance of the barrier.

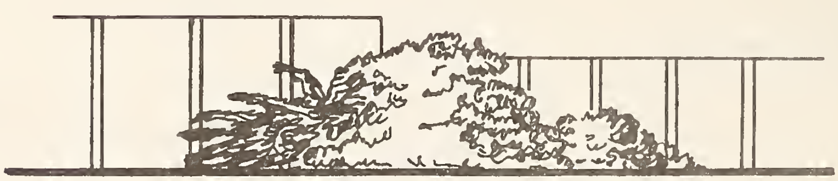
Alternative concepts for changes in the visual form of the barrier are illustrated in Figures 3-20 and 3-21. Some of the major options open to the highway designer include straight barrier wall, straight barrier wall with variation in depth, height and panels, and a barrier wall with curvilinear form.

A second major concept in varying the form of barrier walls is with a diversity of wall type to give visual relief to the barrier. Basically this concept involves working with the barrier wall and landscaped earth berms to provide both continued acoustic attenuation and visual diversity along the length of the barrier (Figure 3-22).

From both a visual and safety standpoint, barrier walls should not begin or end abruptly. A gradual transition from the ground plane to desired height can be achieved several ways. One concept is to begin or terminate the wall in an earth



CREATING A VARIETY OF SPACES



LINKING DIFFERENT SIZE WALLS

FIGURE 3-20. VARYING THE VISUAL FORM

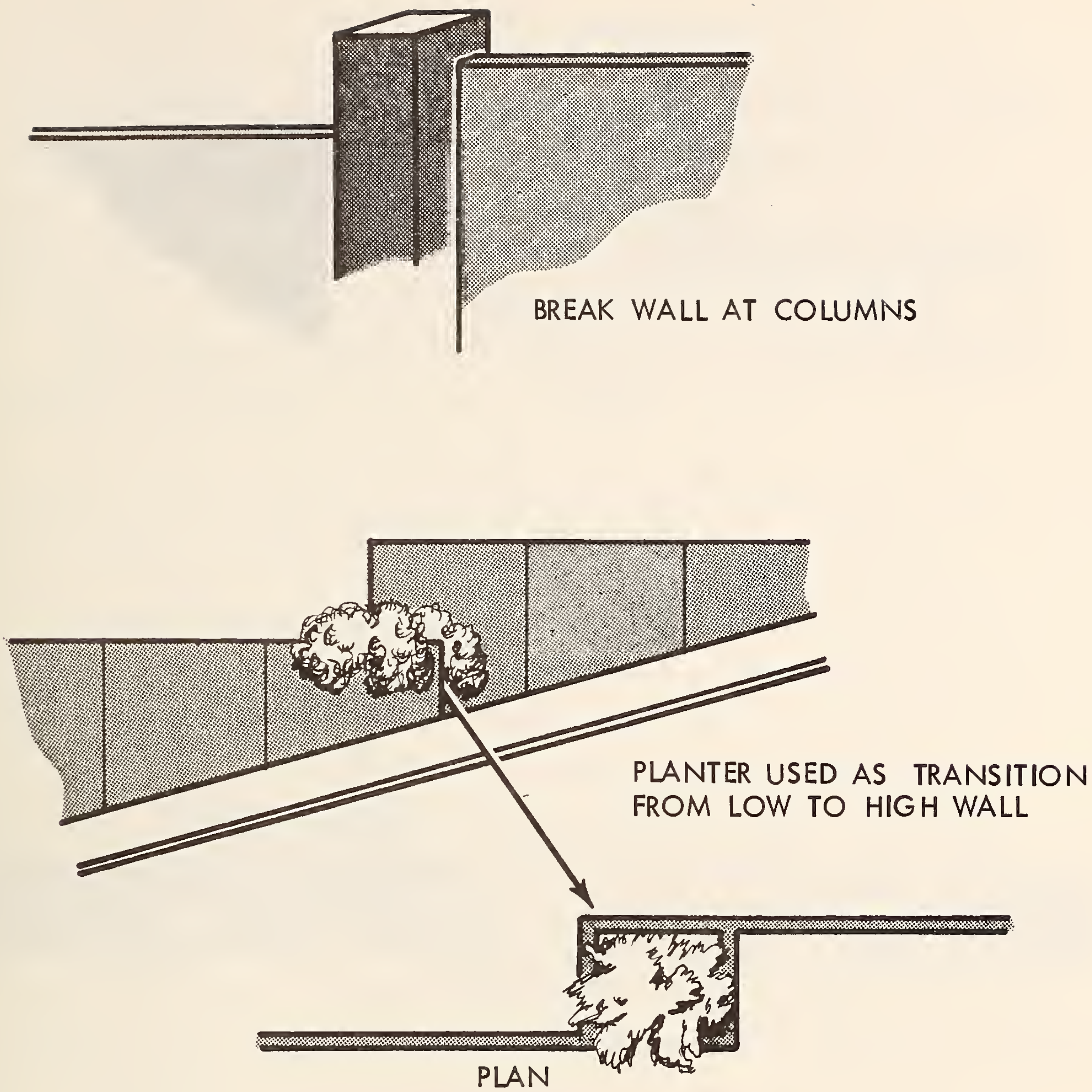


FIGURE 3-21. CONNECTING DIFFERENT HEIGHT WALLS TO VARY VISUAL FORM

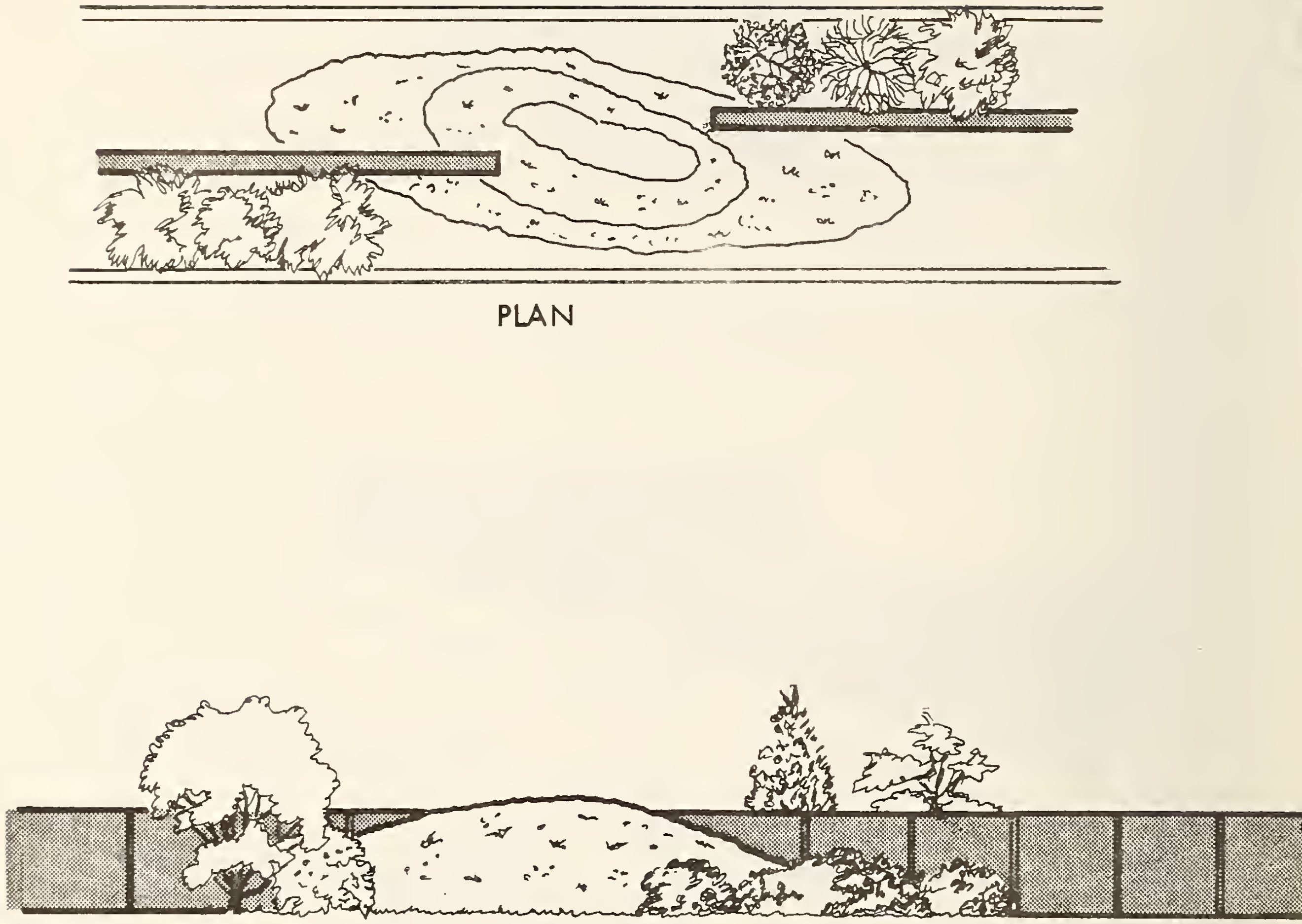


FIGURE 3-22. USE OF BERM TO CONNECT WALLS AND ADD VARIETY

berm mound. Other concepts include bending back and sloping the wall, curving the wall back in a transition form, stepping the wall down in height, and terminating in a wall planter. The concept of terminating the wall with a planter should be utilized only in areas where the edges will be protected from potential conflict with highway traffic. These approaches are illustrated in Figures 3-23, 3-24, and 3-25.

3-6 Materials and Designs

A variety of materials may be used for noise barriers. The approach taken in this handbook is to provide detailed engineering designs, called "reference drawings," for several materials which have been used as noise barriers with good results: concrete, masonry, steel and wood for barrier walls, and earth berms. These drawings may be found in Appendix A. Each of the basic materials under consideration is first presented in reference drawing format with subsequent modifications for various alternative surface treatments for visual and weathering purposes. Appendix B provides similar drawings for steel and wood walls designed specifically for use on elevated structures. Finally, reference drawings are provided in Appendix C for sound absorbing treatments which may be applied to barrier walls.

Due to the extreme variations and conditions encountered throughout the country, it is not possible to prepare a standardized wall construction detail which is applicable in every locality and for the entire scope of any individual

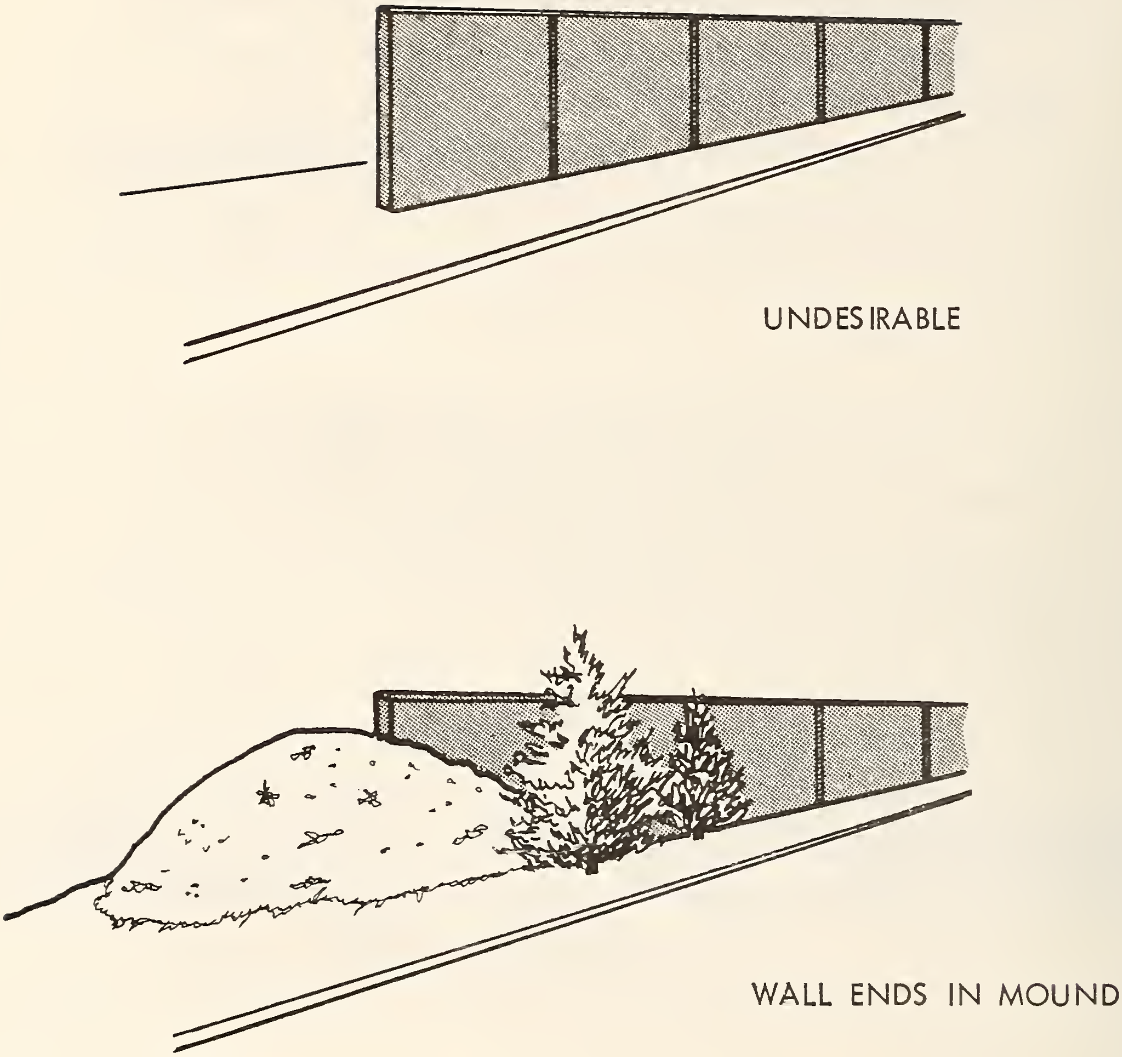
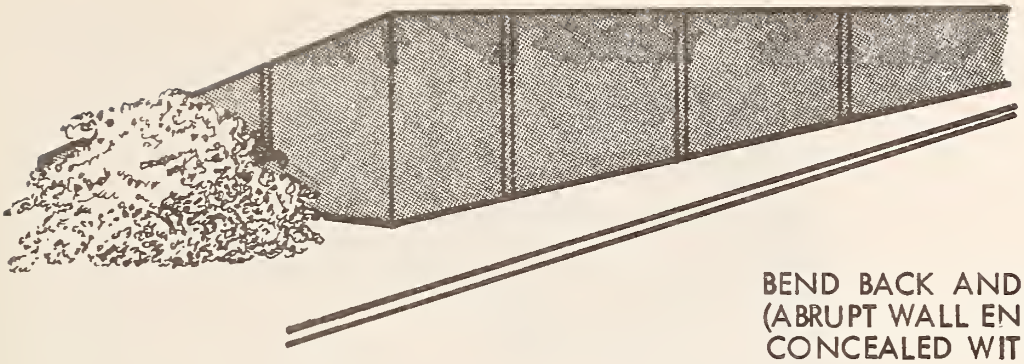
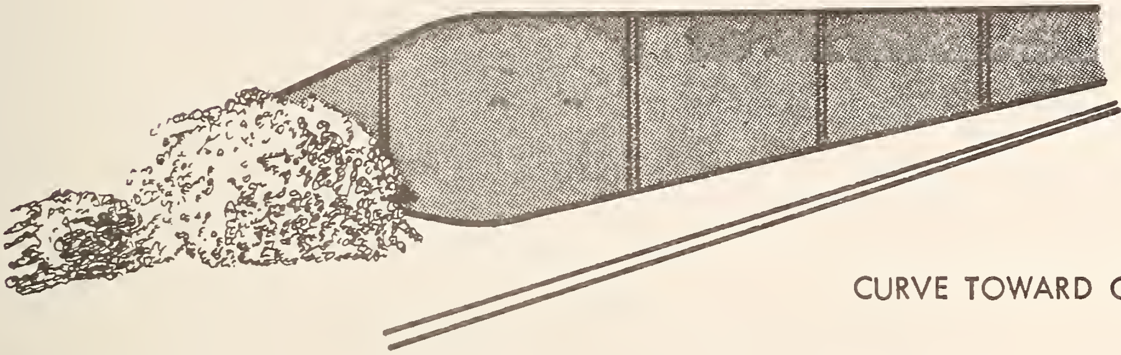


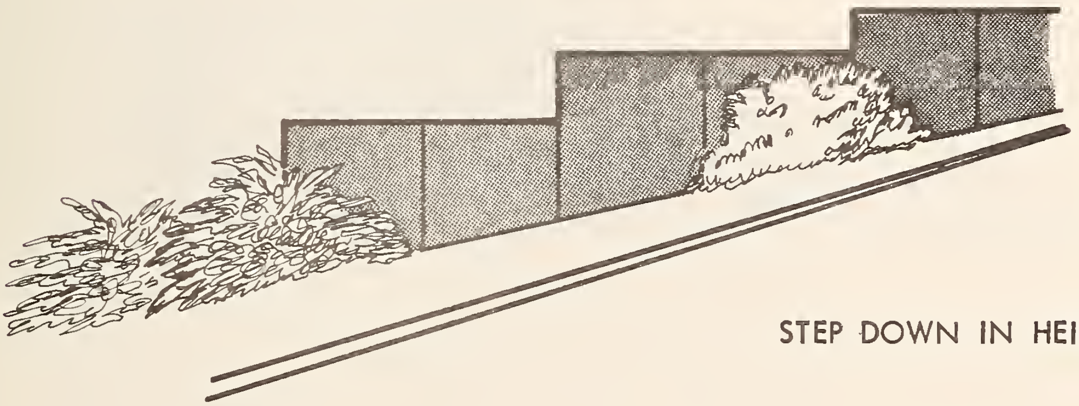
FIGURE 3-23. USE OF EARTH MOUND TO TERMINATE WALL



BEND BACK AND SLOPE
(ABRUPT WALL ENDS CAN BE
CONCEALED WITH PLANTS)



CURVE TOWARD GROUND



STEP DOWN IN HEIGHT

FIGURE 3-24. ALTERNATE MEANS OF TERMINATING BARRIER WALLS

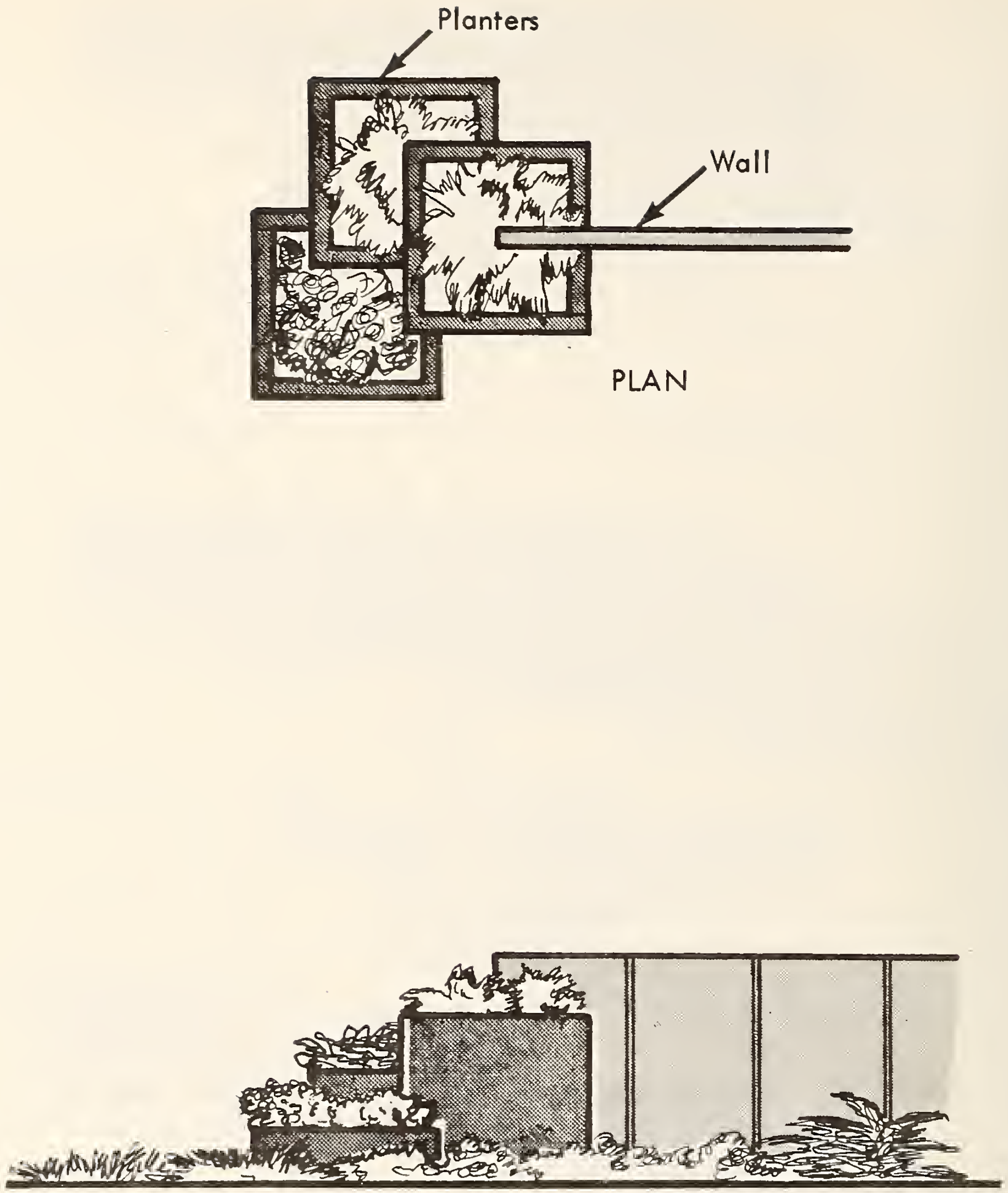


FIGURE 3-25. USE OF PLANTER TO TERMINATE WALL
(in protected areas only)

project. However, generalized criteria have been utilized in the design of all barriers which may be applicable to a great number of highway design projects. As indicated on the reference drawings, each wall system has been designed for heights of five, ten, fifteen, and twenty feet. In addition, appropriate wall designs are provided for wind loadings of twenty, thirty, and forty pounds per square foot. It must be understood by the highway designer that each project will need to be designed for the specific wind, soils, and other conditions encountered for that project unless the conditions conform to those outlined in the design criteria indicated on the specific reference drawings.

In addition, the AASHTO guide "Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals" (Reference 3-4) should be considered by the designer and used as appropriate.

In general, the wall systems have been designed to span horizontally between columns with pier support foundations. The rationale for this design approach is to allow the highway designer the greatest flexibility in wall placement and location and to avoid problems of varying horizontal and vertical alignments of the highway. The basic wall type reference drawing incorporates the following information: the height of the wall; the spacing between columns; the depth of the foundation pier support; the diameter of the foundation piers; the size of the column supports; and the size of the thickness of the material of the basic wall structure. This information is presented for the three typical wind loading conditions.

The structural design criteria have excluded consideration of vehicle impact since in many situations, the barrier wall will be located either behind crash barriers or sufficiently far from the traveled way to eliminate the need for crash barrier protection. If the local project, due to limited right-of-way, requires the placement of the acoustic barrier closer than thirty feet from the edge of the traveled way, the highway designer may wish to either provide a separate guard rail or crash barrier or, alternatively, utilize the potential crash situation as the design criteria for structural design of the acoustic barrier. Snow loads are a localized condition and should be considered by the highway designer. Consideration should also be given to providing drainage under the barrier.

3-6.1 Concrete Barriers

The basic wall configuration developed for concrete barriers is a system of four inch thick precast concrete panels, spanning horizontally between poured-in-place concrete piers supported on pier foundations. The basic wall system has been developed as a precast approach due to economic considerations and versatility with respect to varying conditions likely to be encountered by the highway designer. Typically, the precast panels span between poured-in-place columns varying between ten inches square to fifteen inches square, depending upon the height of the wall and the local wind pressures.

An alternative modification of the basic precast concrete wall is to utilize the precast panels spanning between steel columns which are, in turn, set in piers instead of utilizing poured-in-place concrete columns. The advantage of this approach is to minimize the on-site fabrication and forming work required to erect the wall.

Surface treatments for concrete walls offer the highway designer many opportunities for good visual design at a nominal cost. Several are illustrated in Appendix A in Figure C-3. The various surface treatments for concrete walls include forming the concrete with random width boards, form inserts, utilizing a fine line ribbed texture formed by inserting a rubber mat prior to pouring the concrete, and reinforcing bars inserted in the forms for a rough textured surface finish. Another method of achieving a surface texture is through use of "Bomanite" which is a franchised method of press forming concrete slabs. Several patterns are available using this system. Alternative surface approaches would include use of an exposed aggregate surface finish or sandblasting the concrete wall. Due to maintenance considerations, it is generally not desirable to paint the concrete surface. However, if a colored surface is desired, this can be achieved either through an integral color additive mixed with the concrete or through the careful selection of aggregate and cement-type mixes to present a finished wall surface which is visually pleasing.

Additional surface treatment of concrete walls can be accomplished by the highway designer through the surface application of other materials. One example would be the application of pressed wood fiber panels applied to either a new or existing concrete wall to act as an acoustical absorbing material. Other materials which could be applied to a concrete wall include brick veneer, stucco, and similar materials.

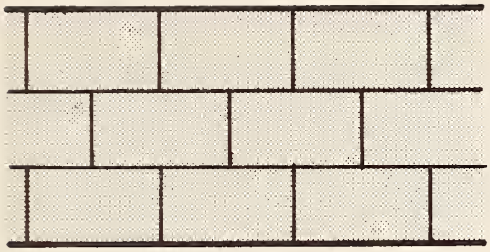
Variation in the horizontal alignment of the concrete barrier wall is desirable both from a visual and functional consideration. One method of offsetting bays of the concrete panels is to place the panel either front-face or rear-face of the concrete piers.

3-6.2 Concrete Masonry Unit Walls

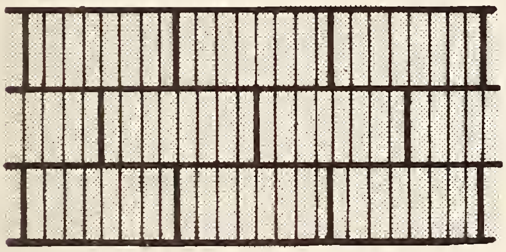
The basic wall configuration for concrete masonry units is based on a six-inch wide by sixteen inches long standard block module. The wall is supported on pier foundations. At each foundation pier, vertical reinforcing steel extends through the hollow cavity of the pier which is then grouted solid to form a column from which the concrete masonry units span horizontally.

A basic concrete masonry unit wall with no surface treatment is generally unacceptable from a visual standpoint. Alternatives to the standard concrete masonry unit wall include utilizing special blocks with scored, combed, or other surface characteristics. Some of the commonly available block designs including slumpstone are illustrated on Figures M-3 and M-4 in Appendix A.

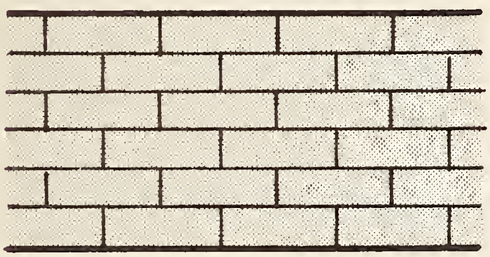
In addition to alternative surface treatment from the standard concrete masonry unit wall, the highway designer may also consider alternative methods of laying up the masonry wall such as stack bond. Various wall patterns as illustrated in Figure 3-26 include common bond, stack bond, and the use of a four inch module. It should be recognized by the highway designer that while special surface blocks normally involve an additional cost, with the scale of many highway projects special blocks could be utilized at nominal additional costs.



COMMON BOND CONCRETE BLOCK WALL TENDS TO BE MONOTONOUS



FIVESCORE BLOCK UNIT WITH INTEGRAL COLOR PROVIDES PLEASING TEXTURE



4" SLUMPSTONE MODULE IN SCALE WITH RESIDENTIAL AREA

FIGURE 3-26. ALTERNATE BLOCK WALL PATTERNS

Another alternative concrete masonry unit wall is constructed in prefabricated panels. In this type, automated block-laying machines can form panels up to twelve feet high and twenty feet long with standard blocks. This type of wall is normally constructed between piers and it is possible to use colored, split-face, single- or multi-score blocks.

3-6.3 Steel Barriers

Steel acoustical barriers are of two basic types. The first type is constructed of steel decking spanning horizontally between steel columns and the second type is made with steel sheet piling which acts as both the wall and the foundation support for the wall.

The basic steel decking wall consists of a ribbed steel deck spot welded to steel columns, as illustrated on Figure S-1. The basic steel deck wall can be modified by adding sheet metal closure strips covering the spot weld joints and a cap rail if so desired by the highway designer. An alternative approach to the basic wall configuration is to construct channel sections on top and bottom spanning between columns; then the sheet metal decking would span vertically between the channel sections.

The barrier wall constructed of sheet steel piling offers the highway designer considerable flexibility in vertical and horizontal alignment in that the individual sections of sheet piling act as their own foundations for the wall. The vertical lines of the sheet piling can be visually attractive.

Surface finishes for the steel barriers can be weathering steel such as "Corten" which is allowed to oxidize and requires no further maintenance. Care should be taken in utilizing weathering steel in relationship to concrete, in that during the initial oxidation period, it can leave streaks. Alternatively, both the sheet metal decking and the sheet piling can be painted.

3-6.4 Wood Barriers

The basic wood barrier indicated on the reference drawings uses two inch thick tongue-in-groove decking to span horizontally between wood posts which in turn are anchored to concrete pier foundations. The use of wood can be a visually pleasing warm material alongside the highway.

Specific surface treatments to improve the visual appearance of the wood wall include placing a top rail and random-spaced vertical battens along the length of the wall. Another concept is to utilize rough-sawn and textured plywood patterns as shown on Figure W-2.

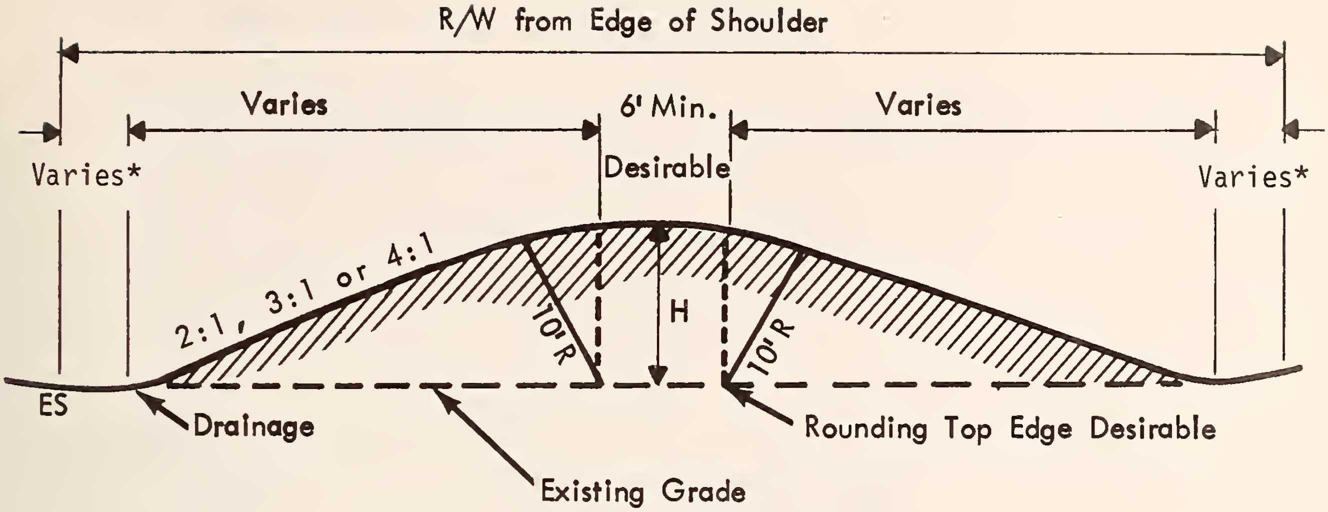
There are several alternative methods of treating the wood walls to protect them from exposure to the elements including utilizing wood preservative, staining, and letting the wood age naturally. Letting the wood age naturally is only suggested for wood such as redwood and cedar which will accept this kind of exposure. Due to long-term maintenance considerations, painting of the wood wall is not suggested.

3-6.5 Earth Berms

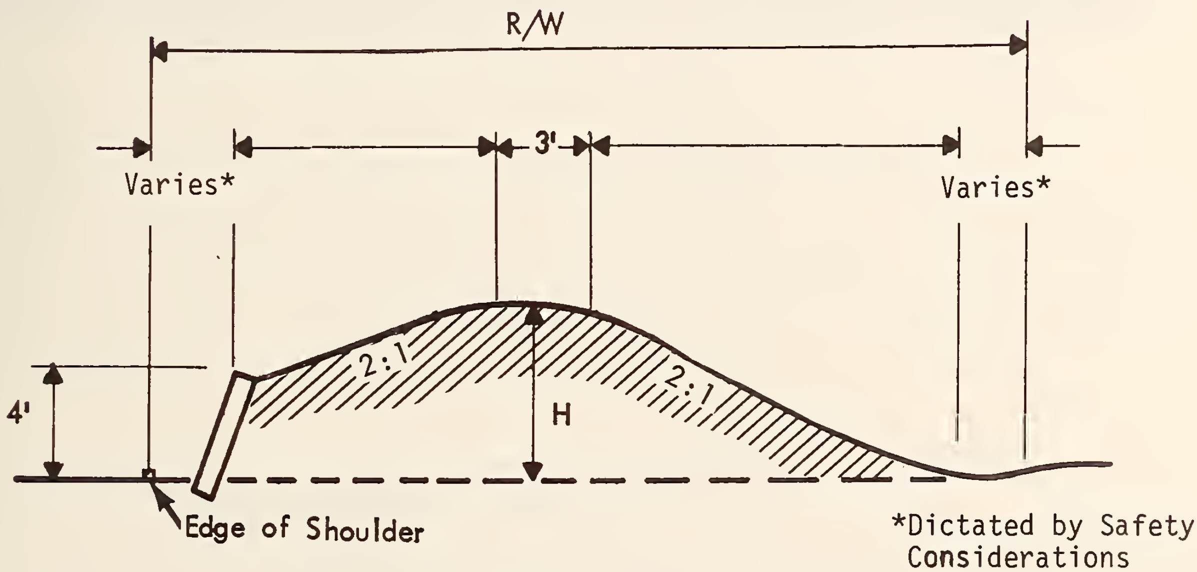
Planted earth berms are usually superior to barrier walls from aesthetic considerations and may be more economical if fill material and right-of-way are available. Slopes of 4:1 or flatter are best from a visual point of view but 2:1 slopes are acceptable if the circumstances warrant.

The main disadvantage of berming is that large areas of right-of-way are required for mounds of significant height. Combining walls and berms allows for more height in a limited right-of-way and more flexibility in the location of walls (see Figures 3-27 and 3-28). In situations where right-of-way width does not permit adequate mounding to occur, a wall built on top of a mound extends its height. In most cases this would cost less than a wall of equal height and increases the aesthetic possiblities. Berms can also serve as connecting points for walls or walls of different heights adding variety to possible severe directional design.

It should be noted however that there is at present serious concern in the scientific community that extensive landscaping along the top of a berm can degrade its attenuation characteristics by scattering the diffracted sound energy. This phenomenon merits further investigation. For the present it is recommended that landscaping along the top of berms be kept to a minimum.



TYPICAL BERM CONFIGURATION



BERM IN LIMITED RIGHT-OF-WAY

FIGURE 3-27. ALTERNATE APPROACHES TO BERM CONSTRUCTION

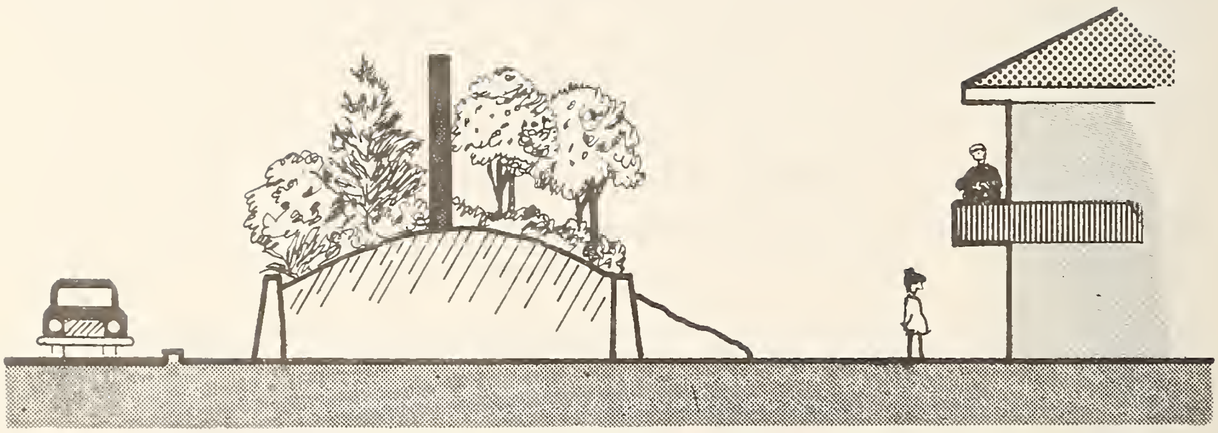


FIGURE 3-28. WALL AND BERM COMBINED TO CREATE MORE HEIGHT IN LIMITED RIGHT-OF-WAY

3-6.6 Noise Barriers for Elevated Structures

The two basic barriers suitable for use on elevated structures are wood barriers and steel barriers. Due to weight considerations, concrete and concrete masonry are not suitable. The conditions of use encountered by the highway designer for noise barriers on elevated structures include bridges, ramps, and elevated roadway grade separations.

It is quite possible that many of these noise barriers will be implemented on existing structures in which there are several factors to be taken into account by the highway designer. One factor is shy distance: there should be a minimum of four feet from the edge of the traveled way to the barrier for adequate shy distance. The second major factor to be considered on existing structures is the structural design of the existing bridge or ramp. If in the original design the horizontal loading forces calculated for the guardrail are equal to or greater than the forces generated by placing the noise barrier and associated wind loads, then the existing structure may be suitable for installation of the barrier. In addition, it will be necessary to evaluate the existing structure to determine if sufficient surface area along its edge is available to adequately anchor the barrier.

3-6.7 Absorption Treatments for Noise Barriers

There are four basic materials which have been considered for absorption treatments to be used with noise barriers. These absorption treatments are resonant cavity concrete masonry units, glass fiber batts, wood fiber planks, and spray-on treatments such as vermiculite or perlite aggregate concrete.

Resonant cavity concrete masonry units are suitable for both free-standing acoustic barrier walls and for an absorptive treatment in locations such as tunnels and underpasses. The concrete masonry units are a standard concrete masonry block with slotted apertures to allow a resonance inside the block. This type of block is a proprietary product called "Soundblox," as manufactured by the Proudfoot Company.

Glass fiber batts are a suitable material for use on free-standing acoustic barriers, tunnels, and underpasses. The glass fiber batts are two inches nominal thickness, one and a half pound cubic foot density and wrapped in a protective covering of 1.5 mil thickness mylar. The batts then are stapled to wood runners which allow a minimum two inches air space behind the glass fiber batts. The front face of the glass fiber batts is protected by the use of random wood battens which leave a minimum surface area opening of 50%, or alternatively by perforated metal panels which have an open area equal to a minimum of 30 to 40% of the surface area.

The third type of acoustic absorption material is pressed wood fiber boards. To be suitable for use in an exterior location this material should be manufactured with a suitable binder and protected from deterioration weathering by the use of exterior non-bridging type latex paint. The pressed wood boards should also be treated with fire-retardant chemicals in the manufacturing process. These boards may be nailed or attached directly to the supporting structural system, allowing a six to sixteen inch air space behind the board for optimum performance. In addition, the wood fiber boards should be located where they are not subject to road splash. It must be emphasized that, while several wood fiber planks are available, the feasibility for exposure to weathering and cleaning must be verified for the specific product under consideration.

The fourth type of acoustical absorption material is a spray-on system of Portland cement concrete with a lightweight perlite or vermiculite aggregate. This product may be sprayed onto a high rib metal lath which in turn maintains a two-inch air space behind the material. Due to the possibility of this material spalling in freezing temperature, it is not recommended for use where exposed to saturation, then freezing. This material should also be protected by the use of a non-bridging exterior latex paint or silicone treatment.

3-6.8 Other Materials

The materials for which reference drawings have been prepared are by no means the only materials which can be used for noise barriers. Information about various other materials is also provided in Chapter 4.

In the design of barriers using these materials, the highway designer may use the reference drawings to provide guidance. Care should be taken to minimize the possibility of openings in the barriers.

Reference 1-4 provides a catalogue of sound absorbing materials which may be used along highways. Additional sound absorbing treatments may be selected from that report. The report also provides further details of the weathering properties of the various materials.

3-7 Costs

A "cost factor" in dollars per lineal foot has been developed for each wall design on each reference drawing. These cost factors include the cost of barrier construction, but not the cost of any right-of-way acquisition or easement purchase. Also, no attempt has been made to quantify the costs of maintenance of a particular barrier.

The primary use of the cost factors is to compare the relative costs of several barrier design options. Since the cost of barrier construction is one of the major considerations in the decision-making process, a rank ordering of alternate design options by cost factor may be very useful in selecting an optimum barrier design.

The cost factors may also be used to estimate total barrier costs for preliminary planning purposes (but the assumptions used to develop the cost factors should be clearly understood, as discussed below). When a final design has been selected and refined, an accurate cost estimate should be prepared by the designer.

For materials not included in the reference drawings, cost factors (on a square foot basis) are also provided. While the cost factors for the reference drawings were determined by evaluation of all the construction details, the cost factors for the other materials were approximated and may not include the costs of structural members for some designs. Thus, care should be taken in using these approximate cost factors, particularly for estimating total barrier costs.

The cost factors indicated on the reference drawings are based on a cost factor of 1.00 = $1.00 per lineal foot of barrier wall in 1975 dollars. To provide this cost estimate, several assumptions have been necessary: costs are based on San Francisco Bay Region prices; the project size is 3,000 lineal feet; and there has been no allowance for traffic detouring. The material necessary for construction of the earth berm is considered to be imported from a distance of five miles.

In order for the cost factor estimates to be properly utilized, the highway designer will have to adjust for the particular geographical location in accordance with the data provided in Chapter 4 relating relative costs in 105 cities around the country. In addition, costs should be escalated from 1975 dollars to the time of construction.

As an indication of the costs of the basic barrier designs provided in the reference drawings, Figure 3-29 shows the cost factors for the various designs as a function of height (using a wind loading of 30 pounds per square foot as an example). Figure 3-30 illustrates the increased costs (based on a 15 foot high barrier) when various aesthetic and/or weathering treatments are applied. These treatments are detailed in Appendix A. Note that fairly simple and inexpensive treatments (such as painting or staining) have not been included on the figure.

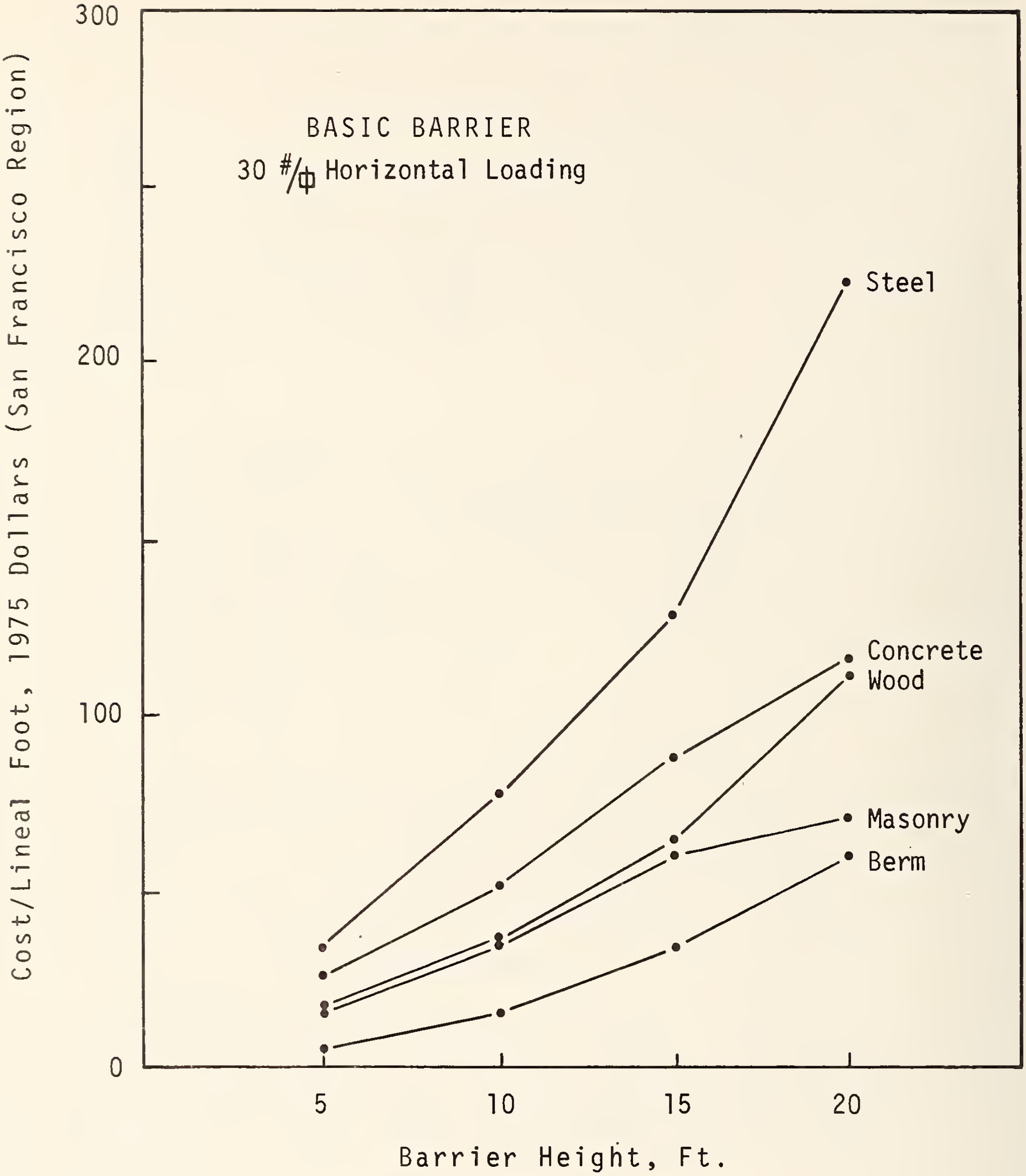


FIGURE 3-29 Construction Costs for Various Barriers.

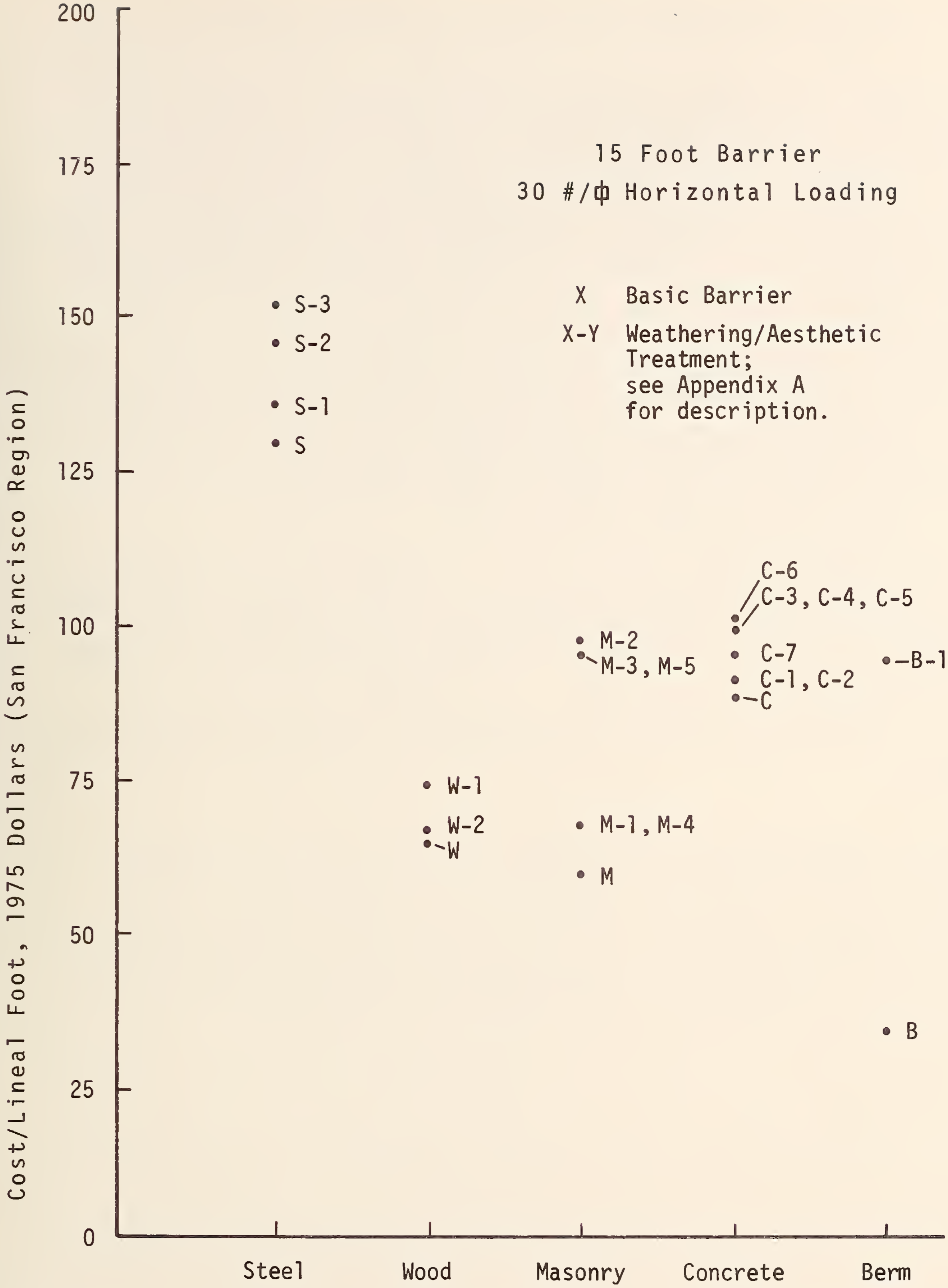


FIGURE 3-30 Construction Costs for Barriers with Additional Treatments.

3-8 Community Participation in the Barrier Design Process

Highway noise exposure in community areas adjoining major facilities can cause annoyance, interference with speech and sleep, and disruption of work and recreational activities. It can create feelings of dissatisfaction with the community, and aggrevate a resident's attitudes toward the highway. While construction of a noise barrier which reduces this exposure may provide significant relief, a barrier which is poorly designed from the point of view of aesthetics, or which creates unpleasant visual impacts because of out-of-scale proportions can further aggrevate the community and in some instances add to the feeling of isolation that may have been created when the facility was first constructed.

By permiting active community participation in the development of barrier plans, beyond the minimum requirements for public hearings, there is greater likelihood that the barrier would be accepted and appreciated. As indicated in Figure 3-1, this involvement should be incorporated throughout the design process.

Public involvement should begin early, in the stage where various noise abatement options are being explored. For a particular community, use of a barrier wall may not be desirable; this type of information is only obtained through knowledge of community attitudes and preferances.

Once the desirability of a noise barrier has been established, consideration of community additudes and desires will help set design criteria. If it is known that the community views its noise exposure as being severe, then reducing that exposure by a few decibels to meet specific noise standards (although complying with appropriate regulations) will do little to solve the community's problem and will only result in a waste of funds and a loss of credibility.

Selection of barrier location, materials, and ultimate design can benefit from community involvement and review. Not only will a better understanding of community preferances be gained by the highway designer, but an understanding of the available options as well as constraints facing the designer will be gained by the community. This mutual understanding of community needs and attitudes and highway design constraints and limitations will greatly enhance the barrier design process.

CHAPTER 4
BARRIER DESIGN PROCEDURE

When faced with the problem of designing a noise barrier to reduce roadway traffic noise to within certain desirable levels, various questions come to mind:

- Where should the barrier be placed?
- How high?
- How long?
- What materials should be used?
- Should it be a wall or berm?

In addition to these questions concerned with the physical characteristics of the barrier, questions concerning the economics and functional performance of the barrier must be answered as well:

- How costly will the barrier be?
- Will it be accepted by the community as well as the highway user?
- Will it create safety problems?
- Will there be any maintenance or durability problems?

Before these questions can be answered, it should be recognized that if it is possible to build a barrier which will provide the required noise reduction, then generally there are many such barriers which will provide the necessary reduction. One approach to the design of a noise barrier, and indeed the approach to be taken in this chapter, is to define all reasonable barriers (or, at least, many such barriers) which will fulfill the required noise reduction, and provide sufficient information about each barrier to permit a rational selection of the barrier most appropriate for a particular set of local conditions.

This chapter details a barrier design procedure incorporating the following major steps:

Step 1: Determine Noise Reduction Design Goals

Step 2: Define Site Characteristics

Step 3: Determine Geometrical Alternatives

Step 4: Identify Additional Barrier Treatments

Step 5: Select Design Options

Step 6: Define Cost Factors

Step 7: Assess Functional Characteristics

Step 8: Select Barrier

Step 9: Design Barrier

These steps form the framework for specification of barrier requirements, determination of barrier options which would satisfy these requirements, and selection of an optimum design based on assessment of acoustic and functional characteristics and cost.

This procedure is intended to be used in conjunction with other tools available to the highway designer according to the following scenario:

Stage I. A current or anticipated highway noise problem is identified. Noise levels are determined using the 117/144 or TSC methodology (or through field measurements), and possibly noise contours are prepared. Noise criteria are established and critical receivers are identified.

Stage II. Among the options considered to reduce noise exposure is the use of noise barriers. Using the design procedure in this chapter the approximate physical dimensions of alternate barriers are determined, several design options are developed and evaluated, and a single design is selected based on its acoustical and non-acoustical characteristics and cost.

Stage III. The physical dimensions of the barrier design are refined and optimized, and a final design is prepared. This process is facilitated by use of the TSC computer program.

The procedures of this chapter specifically address Stage II activities. There are several important points about all three stages that should be emphasized, however. First, in order to begin the procedure that follows the designer must have previously determined "before" noise levels at critical receiver locations. Second, for the purpose of easily defining possible barrier dimensions so that various design options can be developed, the procedure entails a simplified assessment of barrier attenuation, which provides only gross (but conservative) dimensions in terms of necessary height and length. Use of these approximate barrier dimensions is certainly adequate, however, for evaluating and selecting the design options. Finally, only by use of a computer can the myriad highway, traffic and community parameters influencing noise exposure be properly accounted for. Once a design is chosen, the TSC computer program should be used to help optimize barrier dimensions, which should result in a less costly design.

In using the procedure in this chapter, the designer should be guided by the considerations discussed in Chapter 3. Examples of the calculations and of the use of nomographs, charts, etc., are included throughout this chapter; complete examples of the procedure are provided in Chapter 5.

4-1 Step 1: Determine Noise Reduction Design Goals

In this step the desired noise reduction characteristics of the barrier are defined, and their feasibility is evaluated.

1.1 Prepare a route map to a convenient scale. Identify critical receivers along the route where there is a noise impact based on projected or measured noise levels. Select at least six such receiver locations: the closest to the roadway and the farthest from the roadway at both ends of the community and somewhere in the middle of the community (see Figure 3-8).

1.2 Draw a perpendicular from one critical receiver to the roadway center line (if the roadway curves about the receiver so that there is more than one such perpendicular, choose the shortest perpendicular).

1.3 Measure the near-lane distance D_N (distance to the center of the near-lane), and the far-lane distance D_F (distance to the center of the far-lane). Calculate the equivalent lane distance D_E as follows:

$$D_E = \sqrt{D_N \times D_F} \qquad (4\text{-}1)$$

Example. A receiver is located 125 feet from the edge of the near lane of a highway with eight 12-foot lanes and a 30-foot median. The distance to the near lane D_N is 125 + 6 = 131 feet, and to the far lane D_F is 125 + (7 x 12) + 6 + 30 = 245 feet. See Figure 4-1. The equivalent lane distance is thus

$$\sqrt{131 \times 245} = 179 \text{ feet.}$$

1.4 Refer to the Design Goal Worksheet, Figure 4-2. Enter the equivalent lane distance D_E on Line 1.

1.5 Enter on Line 2 the "before" barrier noise level, L_B, in dBA. (Either L_{10} or L_{eq} may be used.)

1.6 Enter on Line 3 the desired criterion level L_C, in dBA (in terms of L_{10} or L_{eq}, whichever was used in Step 1.5).

1.7 The desired insertion loss is given by $L_B - L_C$. Enter on Line 4.

1.8 On Line 5 enter the method by which L_B was determined. Was it 117/144, TSC, or field measurements?

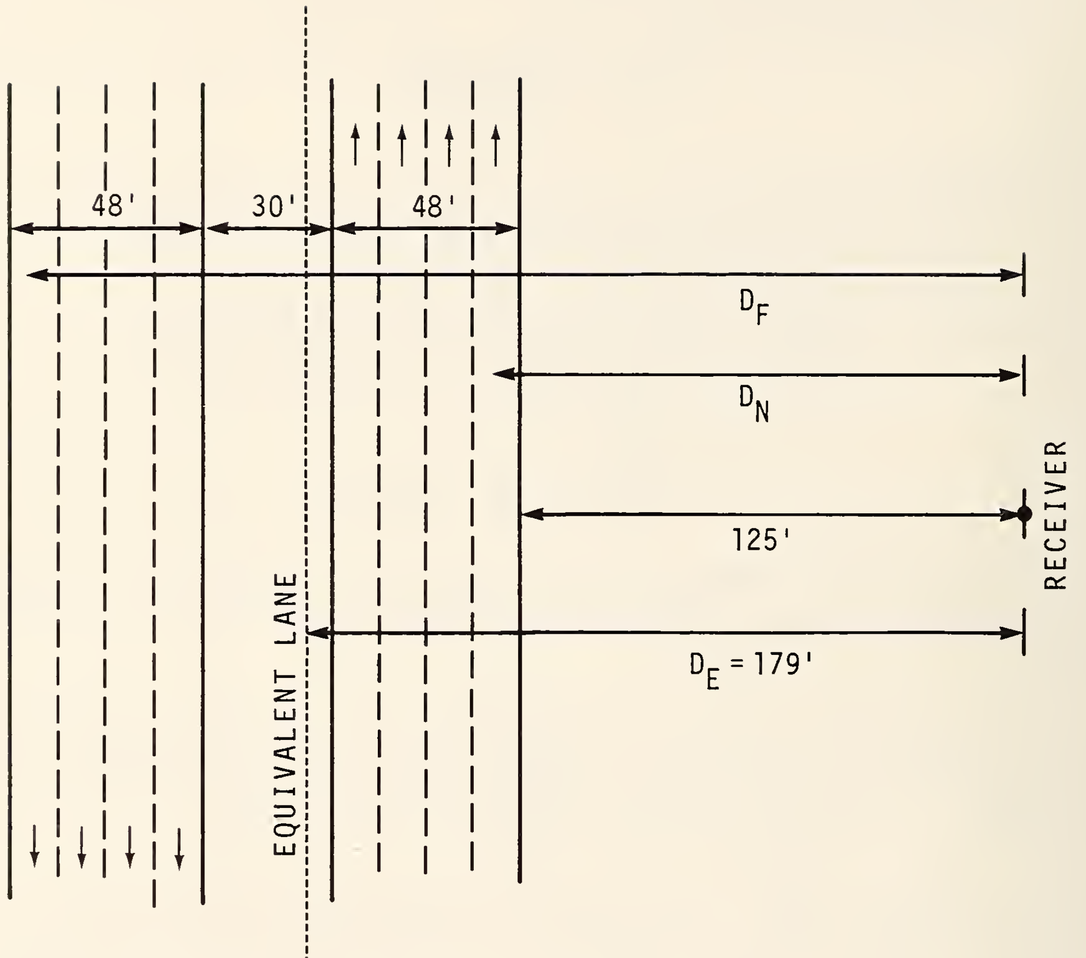


FIGURE 4-1 Receiver / Highway Distance Relationships.

FIGURE 4-2

DESIGN GOAL WORKSHEET

Step	Item	Receiver 1	Receiver 2	Receiver 3	Recevier 4	Receiver 5	Receiver 6
1	D_E, ft						
2	L_B, dBA						
3	L_C, dBA						
4	$L_B - L_C$, dBA						
5	Method						
6	Δ_S, dBA						
7	Δ_G, dBA						
8	NR, dBA						
9	NR $\geq$ 20?						

1.9 If L_B includes the effects of shielding between the source and receiver, determine the magnitude of the shielding attenuation Δ_S (excluding the shielding from houses and vegetation). If the prediction procedure used to determine L_B does not readily indicate Δ_S, it may be determined by predicting L_B with and without the shielding element present. (If field measurements were used, refer to the Barrier Nomograph [Figure 4-13] to estimate the attenuation provided by the shielding element.) Enter Δ_S on Line 6.

1.10 If the TSC method was used to determine L_B, Δ_G is zero. If 117/144 was used, Figure 4-3 indicates Δ_G as a function of the equivalent lane distance D_E. Enter Δ_G on Line 7.

> Example. Assume the 117/144 method was used to determine L_B. For D_E = 179 feet, Δ_G is 2.5 dBA. For D_E = 500 feet and beyond, Δ_G is 5 dBA.

1.11 If L_B was measured at several representative locations in the field, the propagation loss factor for the actual terrain can be determined. If this is closer to 3 dB than to 4.5 dB per doubling of distance, Δ_G = 0. If it is closer to 4.5 dB than to 3 dB, use Figure 4-3 to find Δ_G. Enter on Line 7.

1.12 Determine the Design Goal noise reduction by adding Line 4 to the larger of Lines 6 and 7. Enter on Line 8. (This is the total reduction required to achieve the desired criterion level, <u>not</u> the additional reduction beyond that presently available.)

1.13 If the desired reduction is 20 dB or greater (Line 9), it is not feasible to obtain using a noise barrier. Additional methods of noise control should be considered.

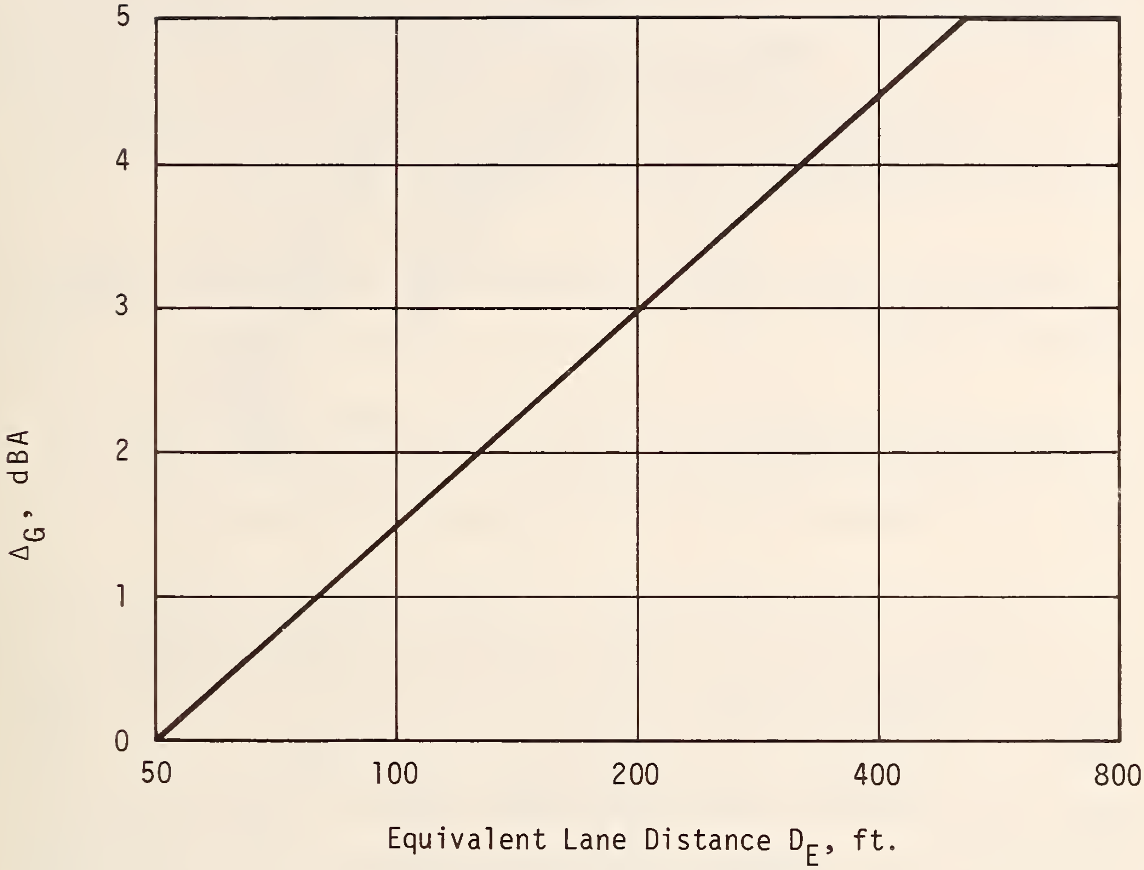


FIGURE 4-3 Ground Effect Attenuation.

1.14 Steps 1.2 through 1.13 should be performed for each critical receiver from the roadway.

4-2 Step 2: Define Site Characteristics

As input to the process of selecting appropriate locations for noise barriers, it is useful to identify those areas along the roadway where barriers cannot be constructed, and to point out the factors that provide constraints on the location or structural requirements of the barrier.

2.1 Delineate the existing right-of-way on the route map prepared in Step 1.

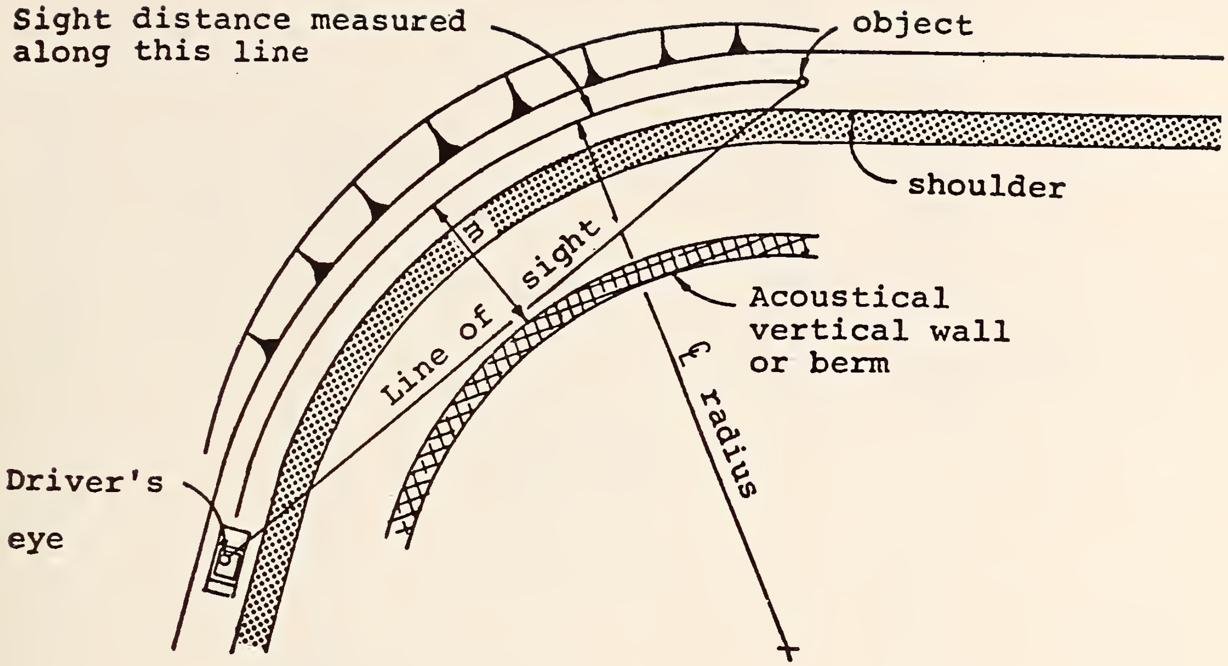
2.2 Delineate those areas beyond the right-of-way which might be acquired through purchase or easements to provide additional locations for noise barriers if necessary.

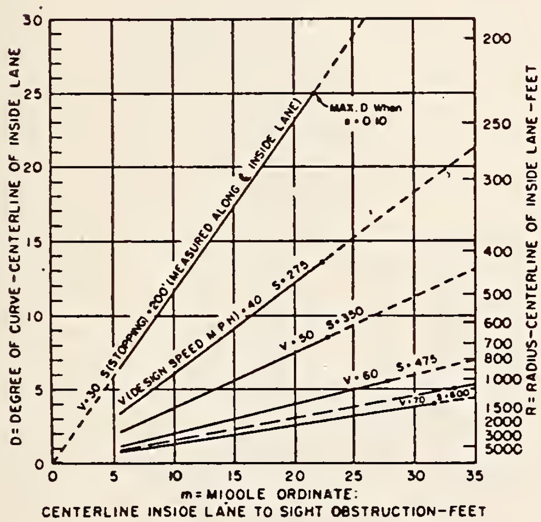
2.3 Identify those areas where a noise barrier should not be constructed because of safety factors, based on the following considerations.

<u>2.3.1</u> For curved on- and off-ramps, refer to Figure 4-4 to determine the minimum setback distance m, as a function of the design speed and radius of curvature of the ramp.

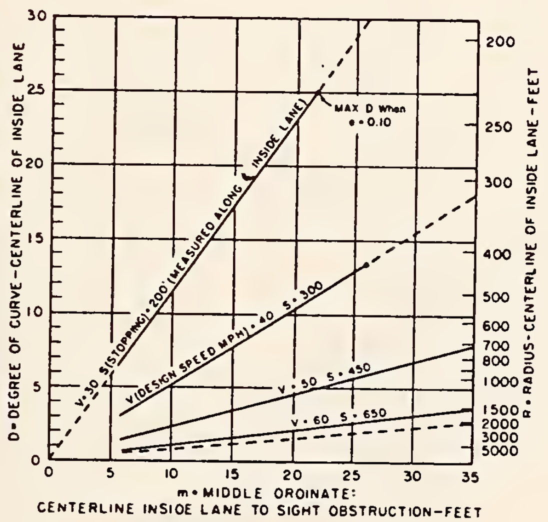
> Example. See Figure 4-5 for an example of safety considerations for an on- or off-ramp.

<u>2.3.2</u> For intersecting ramps, refer to Figure 4-6. Determine the sight distance d along the highway as a function of the design speed. For this setback distance, draw the sight line from the center of the near lane to the eye of the driver on the ramp. A noise barrier should not be located within the area defined by this sight line and the highway.





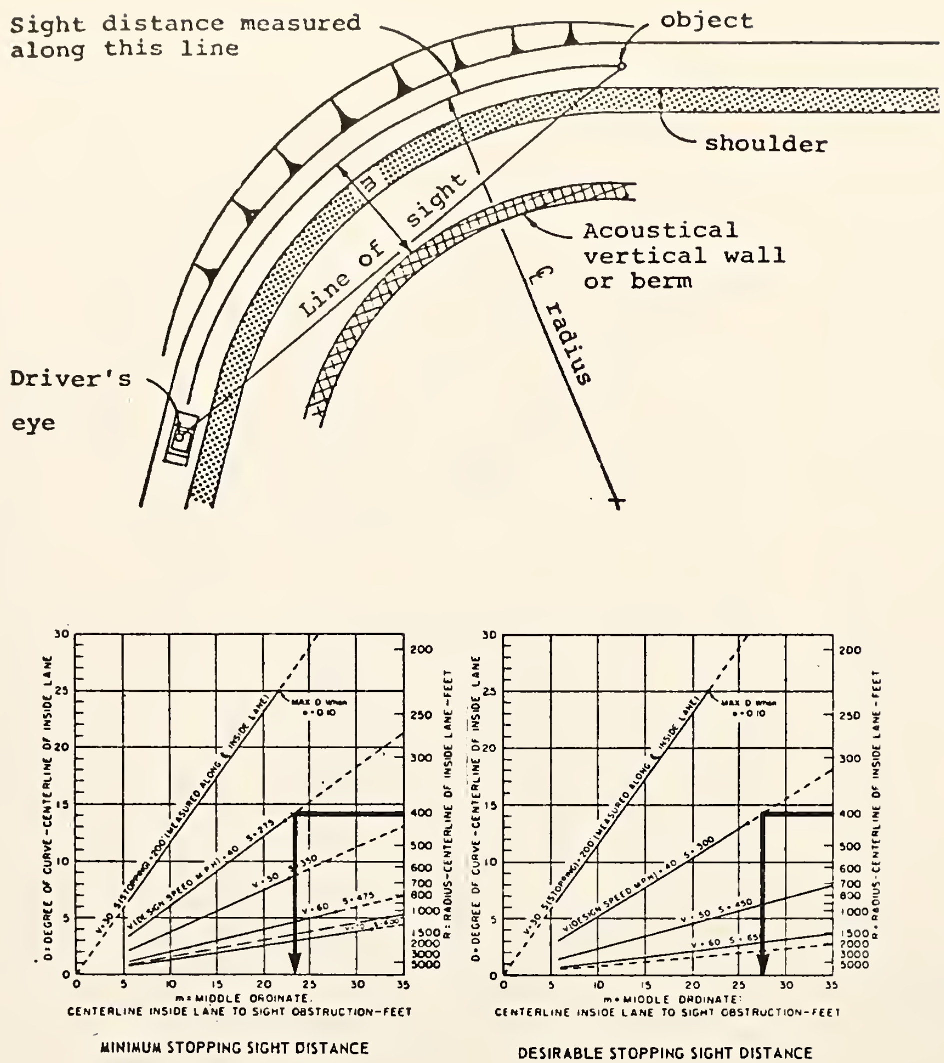
MINIMUM STOPPING SIGHT DISTANCE



DESIRABLE STOPPING SIGHT DISTANCE

(Source: Reference 4-1)

FIGURE 4-4 Safety Factors for On and Off Ramps.



EXAMPLE:

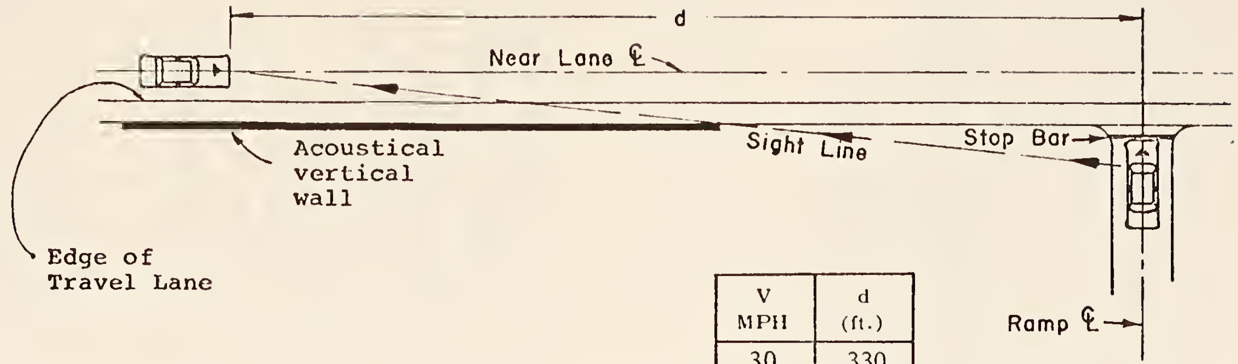
Ramp design speed = 40 mph

Radius of curve = 400 ft

Then for minimum stopping sight distance barrier must be set back 23 feet.

For desirable stopping sight distance barrier must be set back 28 feet.

FIGURE 4-5 Example of Safety Considerations for On and Off Ramps.



V MPH	d (ft.)
30	330
40	440
50	550
60	660

FIGURE 4-6 Safety Factors for Ramp Intersections.

Example. See Figure 4-7 for an example of safety considerations for an intersecting ramp.

2.3.3 For intersecting roadways, refer to Figure 4-8. Draw a line from the design speed on the major road (Axis A) to the design speed on the minor street (Axis B). Select any two sets of coordinates D_1, D_2 along this line and plot on the route map. A straight line through these two locations will be the sight line; a noise barrier should not be located within the area between this sight line and the roadways.

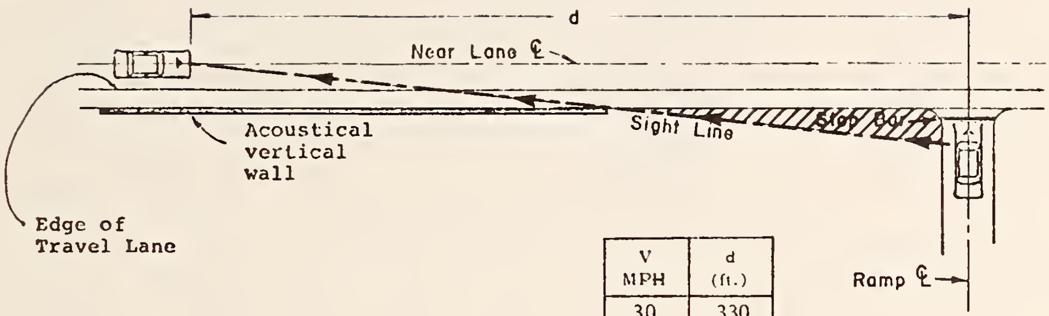
Example. See Figure 4-9 for an example of safety considerations for intersecting roadways.

2.3.4 For bridges and other elevated structures, barriers should be located a minimum of four feet from the edge of the traveled way.

2.4 Examine the area for topographic and neighborhood features which would limit barrier placement or necessitate barrier termination, such as traffic or pedestrian bridges over the roadway, immediately abutting residential dwellings, etc., and note these on the route map.

2.5 Determine wind load requirements and soil characteristics for later use in designing barriers. If appropriate, determine requirements imposed by snow loading.

2.6 If the noise barrier is to be constructed on an existing elevated structure, the structural design of this element should be re-evaluated to determine the suitability for construction of a barrier.



V MPH	d (ft.)
30	330
40	440
50	550
60	660

EXAMPLE:

Road design speed = 60 mph

Then d = 660 feet

Barrier cannot be placed in shaded region.

FIGURE 4-7 Example of Safety Considerations for Ramp Intersections.

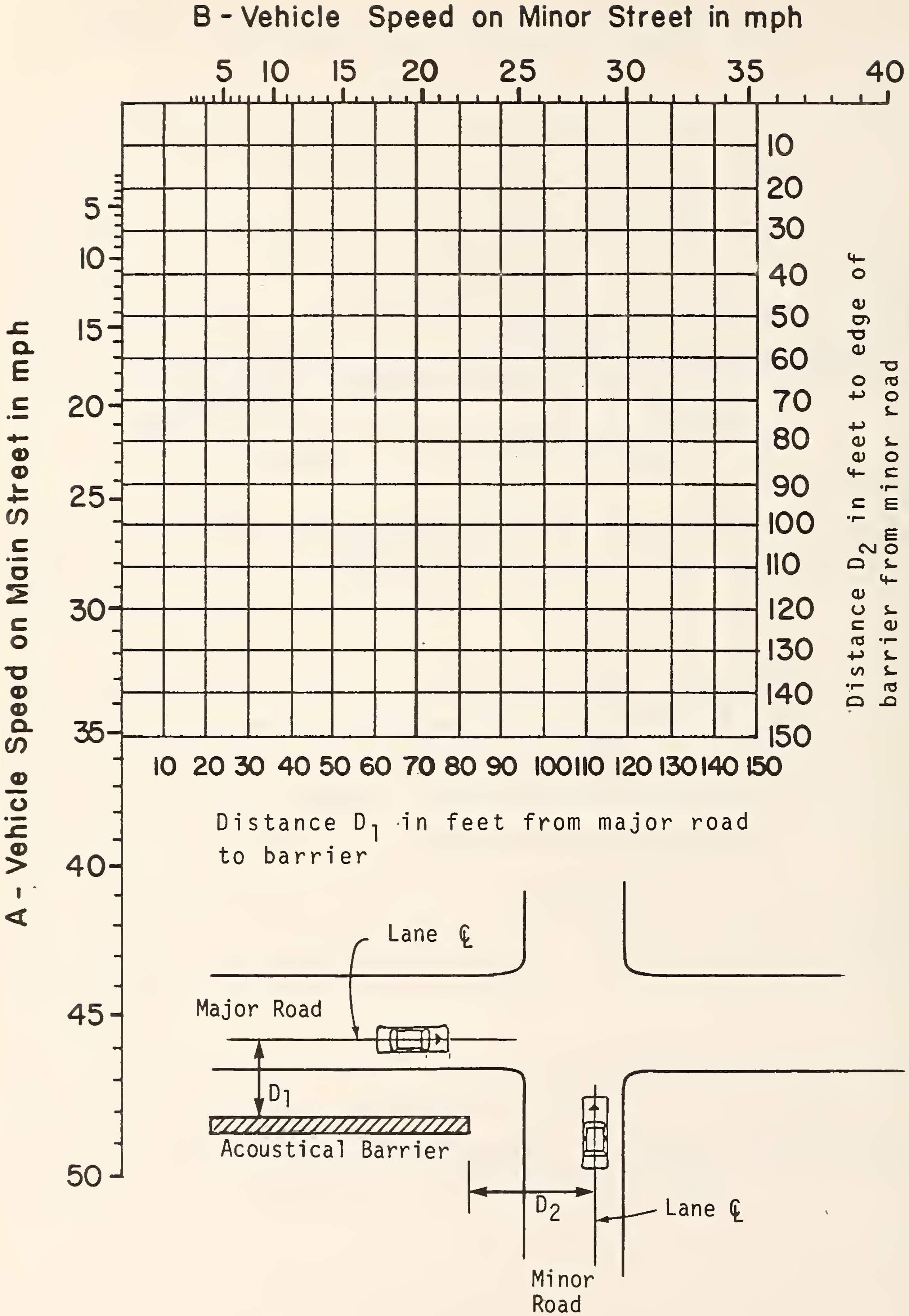
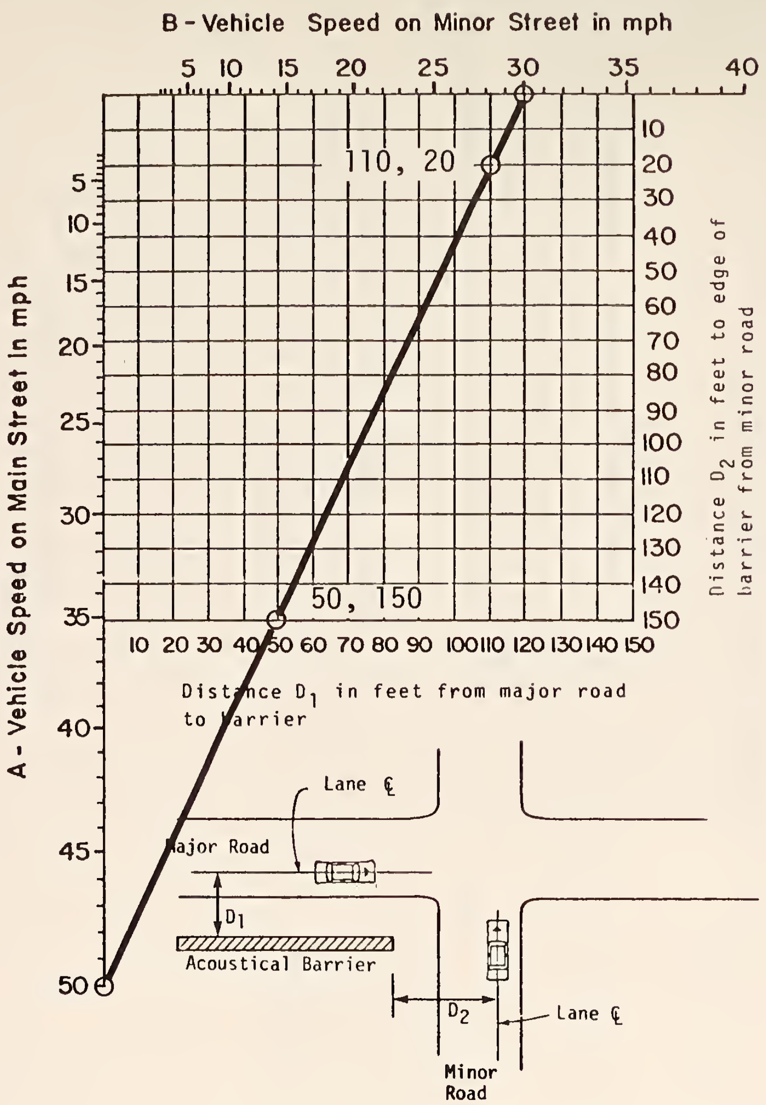


FIGURE 4-8 Safety Factors for Intersecting Roads.

(Based on FIGURE 20-1(a), Ref. 4-2)



EXAMPLE:

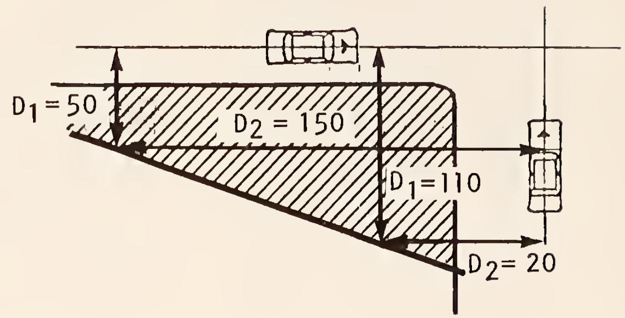
Main Street Speed = 50 mph

Minor Street Speed = 30 mph

Select any two points on the line:

50, 150 and
110, 20

(Not to scale)



Barrier cannot be located in shaded area.

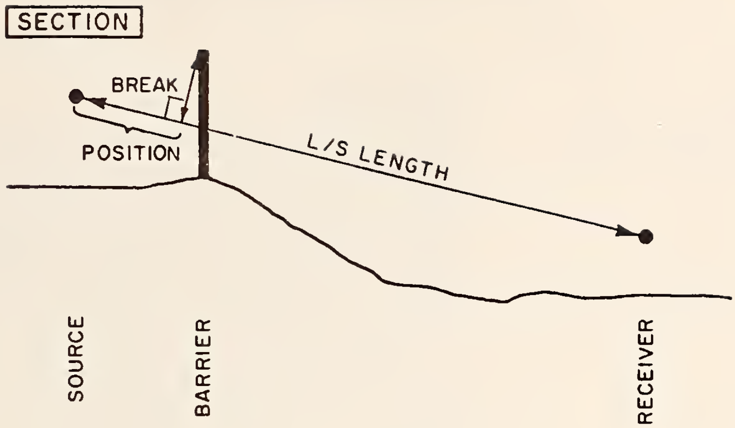
FIGURE 4-9 Example of Safety Considerations for Intersecting Roads.

4-3 Step 3: Determine Geometrical Alternatives

This step provides a methodology for "designing" the noise barrier to achieve the desired reduction goals. In the context of this step, the term "design" refers to determination of the three basic physical dimensions of the barrier which affect its attenuation: its height, its length, and its location or setback relative to the roadway. Several alternative geometrical designs are determined in this step.

At this point it is assumed that the transmission loss of the barrier will be sufficiently high so that the transmitted energy will be insignificant. It is also assumed that there are no multiple reflections from walls across the roadway to compromise barrier performance. Under these circumstances the barrier should be designed for an attenuation equal to the Design Goal noise reduction. If the designer can envision the use of materials with marginal TL properties or a multiple reflection situation, the barrier should be designed in this step for an attenuation higher than the Design Goal noise reduction.

3.1 A nomograph will be used to evaluate barrier attenuation. Use of the nomograph requires knowledge of the following parameters: the line-of-sight distance between the source and the receiver; the break in line-of-sight by the top of the barrier; the barrier position relative to the source and receiver; and the angle subtended by the barrier as seen from the receiver. These parameters are illustrated in Figure 4-10, and defined in Figure 4-11.



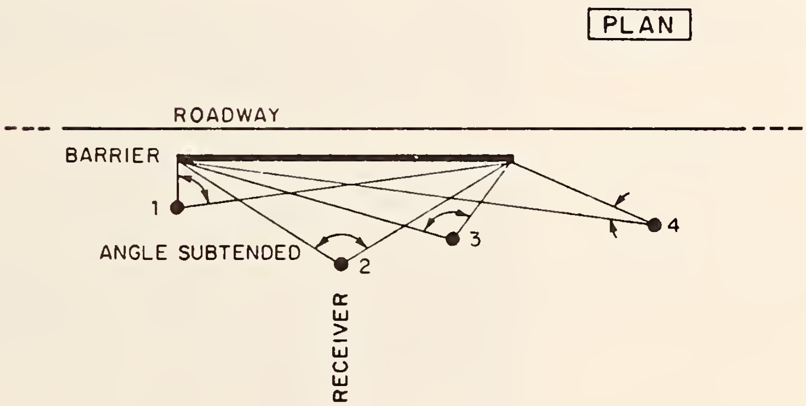


FIGURE 4-10 Illustration of Barrier Parameters.

FIGURE 4-11

DEFINITION OF BARRIER PARAMETERS

Parameter	Definition
Line-of-sight, L/S	Straight line from the receiver to the source of noise. For roadway sources, this L/S is drawn perpendicular to the roadway. At the source end, the L/S must terminate at the proper source height: 0 feet for automobiles and medium trucks, 8 feet for heavy trucks.* At the receiver end, the L/S must terminate at ear height (i.e., 5, 15, 25,...) feet above the ground depending upon the observer location. The L/S distance is the slant-length of the L/S, not the horizontal distance only.
Break in the L/S, B	The perpendicular distance from the top of the barrier to the L/S. If the L/S slants, then this break distance will slant also. This is <u>not</u> the height of the barrier above the terrain.
Barrier position, P	Distance from the perpendicular break point in the L/S to the <u>closer</u> end of the L/S. This is also a slant distance.*
Angle subtended, α	Measured at the receiver in the horizontal plane, the angle subtended by the ends of the barrier. For a barrier always parallel to the roadway, an infinite barrier would subtend 180°. For finite barriers, the angle may also be 180° in the following cases: (1) if the barrier ends bend away from the roadway, so that the actual angle subtended is 180° or more, and (2) if the observer cannot see the roadway past the ends of the barrier, due perhaps to terrain.

*Note that although the "L/S distance" and "barrier position distance" vary slightly for high and low sources, in practice either one may be used. However, the "break in the L/S distance" must be measured accurately for high (heavy truck) and low (automobiles and medium trucks) sources separately.

An overview of the Barrier Nomograph is shown in Figure 4-12. The wavey line in the figure is a representation of the barrier intruding above the line-of-sight, represented by the horizontal line on the bottom of the figure. The barrier can be moved horizontally back and forth, depending upon the barrier position; this horizontal movement is governed by the barrier position scale on the bottom of the figure. The barrier can move up or down, depending upon the barrier break in line-of-sight; the height of the barrier is determined using the barrier break scale on the left of the figure. The top of the barrier falls on a curve of constant attenuation; this attenuation is translated to a numerical value depending upon the angle subtended, using the chart on the right of the figure.

The line-of-sight length is used three times in the nomograph to normalize all distances to the scale of the drawing. The Barrier Nomograph, Figure 4-13, is used to determine the attenuation of a barrier for which L/S, B, P, and α are known as follows:

3.1.1 Starting at the bottom, draw a line from the L/S scale through the Barrier Position scale to Turn A, and project vertically upwards. This line sets the position of the barrier relative to the source and the receiver.

3.1.2 Starting at the left, draw a line from the L/S scale through the Barrier Break in L/S to Turn B, and project horizontally to the right. Where the two lines meet represents the top of the barrier.

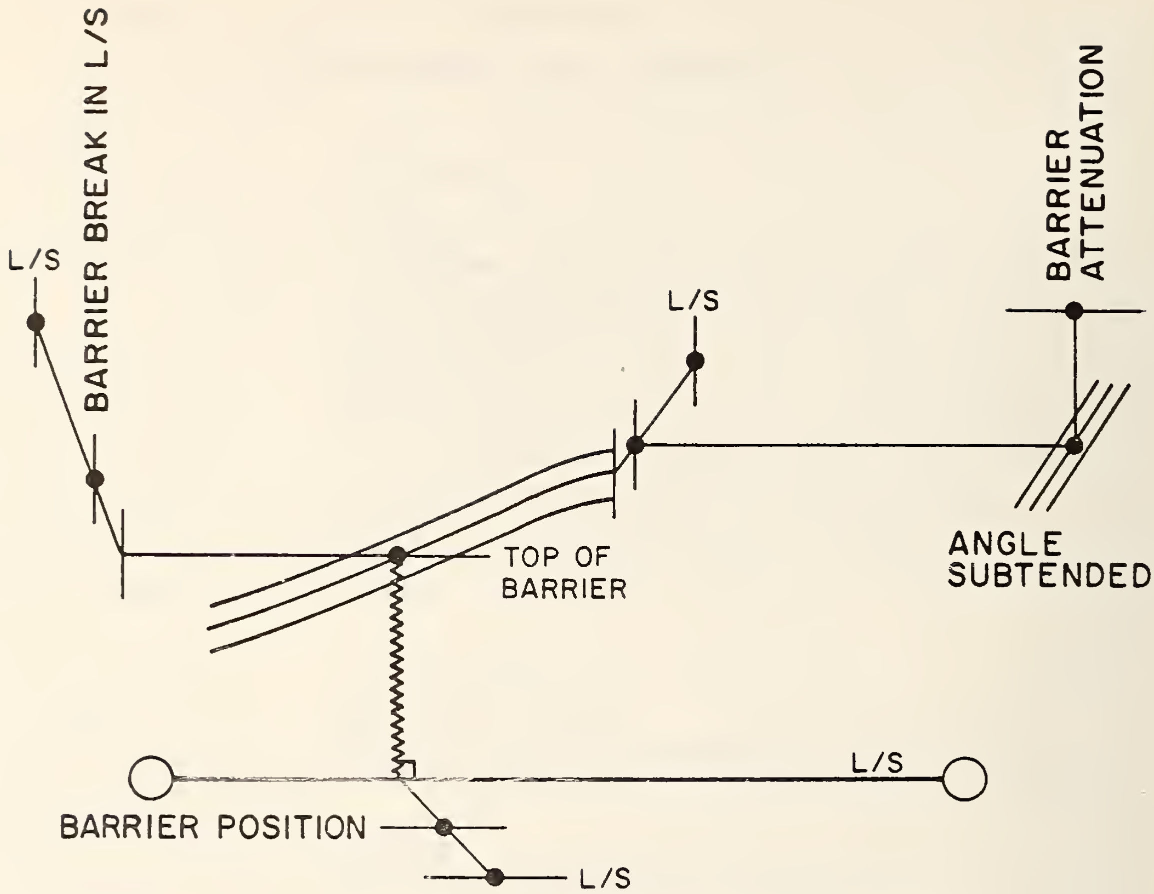


FIGURE 4-12 Overview of Barrier Nomograph.

BARRIER NOMOGRAPH

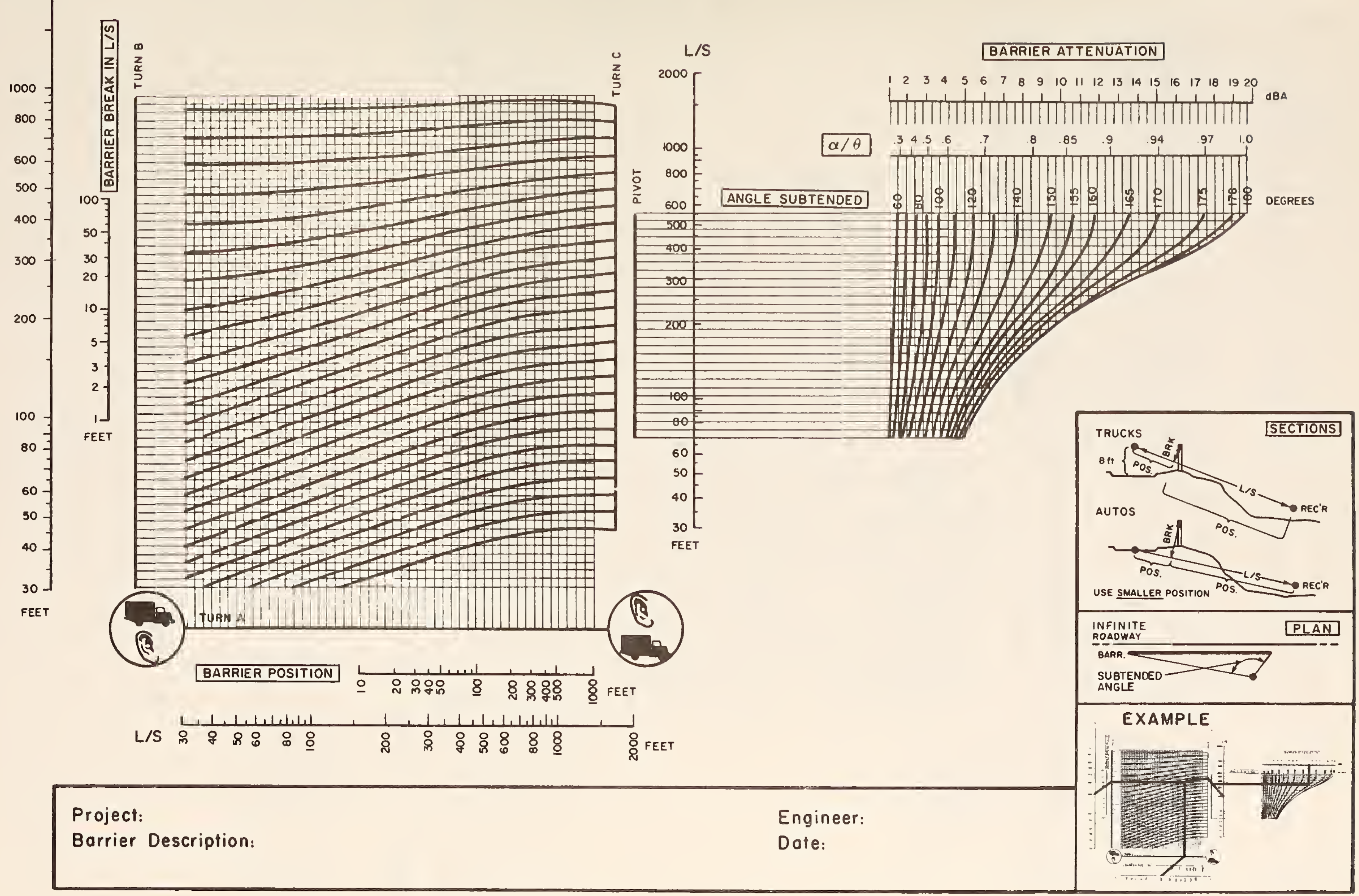


FIGURE 4-13 Nomograph for Determining Barrier Attenuation.

3.1.3 Follow the attenuation curve on which the top of the barrier lies upward and to the right to Turn C, and then connect with the L/S scale in the center of the nomograph.

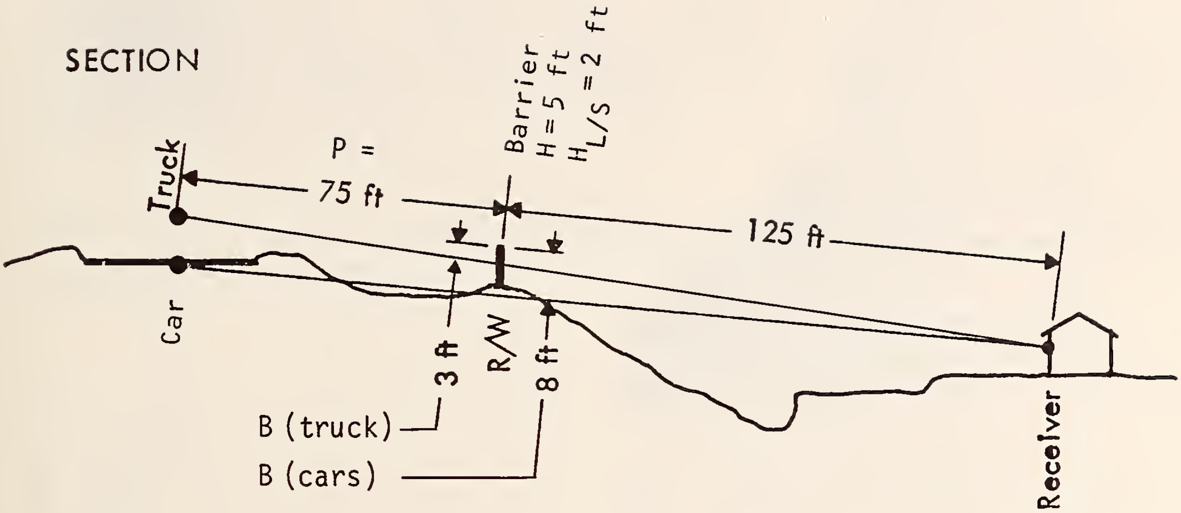
3.1.4 At the intersection of this line with the Pivot line project a line horizontally to the right until it intersects with the curve corresponding to the proper Angle Subtended.

3.1.5 At the intersection with the Angle Subtended curve, project upwards to the Barrier Attenuation scale.

> Example. Figure 4-14 shows a section and plan view of a receiver near a roadway with car and truck traffic; the receiver has a line-of-sight distance of 200 feet to the traffic sources. A barrier is also shown at a position 75 feet from the traffic stream, which provides breaks in line-of-sight of 3 and 8 feet, respectively, for the truck and car sources. Use of the Barrier Nomograph to determine the attenuation provided by this barrier is illustrated in Figure 4-15. For a subtended angle of 170 degrees, the barrier provides 7 dBA attenuation for trucks, and 9½ dBA attenuation for cars.

With some familiarity, use of the barrier nomograph becomes relatively simple and straightforward. Note that the barrier nomograph can be used "backwards" -- for a known attenuation, L/S and P, tradeoffs of B versus α (i.e., barrier height versus length) can be evaluated.

3.2 For the middle closest critical receiver, prepare a cross section through the roadway with uniform horizontal and vertical scales, as follows:



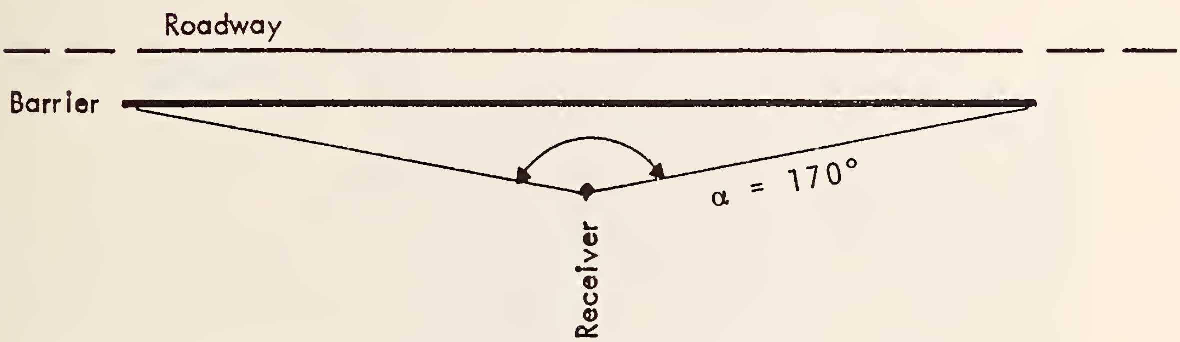


FIGURE 4-14 Barrier Attenuation Example.

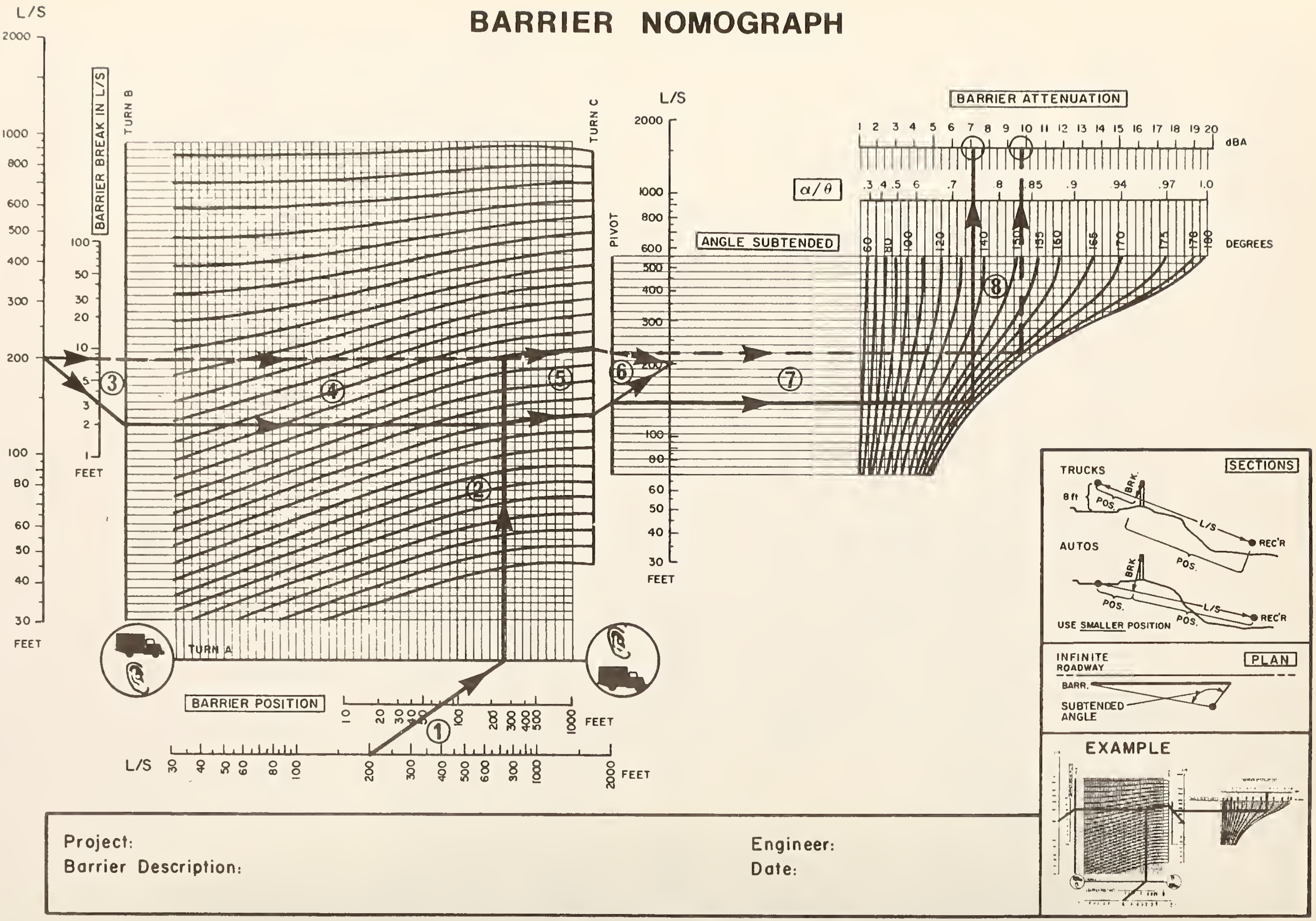


FIGURE 4-15 Use of Barrier Nomograph.

3.2.1 Place the receiver at an appropriate height (5 feet above ground level or above floor level for receivers in multi-story buildings).

3.2.2 Locate the roadway at a distance D_E from the receiver. Locate a source at roadway grade level (0 feet), and at 8 feet above roadway grade. Label these as car and truck sources, respectively.

3.2.3 Include the terrain characteristics between the roadway and the receivers.

3.3 Based on review of the route map prepared under Step 2, determine the closest position to the roadway at which a barrier could reasonably be placed. Measure the parameters L/S and P for truck sources.

3.4 Refer to the Design Goal Worksheet for the Design Goal reduction. Select a trial Design Goal for truck attenuation, Δ(truck), by subtracting 2 dB from the Design Goal for the total attenuation.

3.5 Since a barrier which just breaks the line-of-sight provides about 5 dB attenuation, and each additional foot of height provides about an additional 1/2 dB, select a trial barrier height as follows:

$$H = H_{L/S} + \Delta H \qquad (4\text{-}2)$$

where $H_{L/S}$ is the height up to the intersection with the line-of-sight to truck sources, and

$$\Delta H = (\text{Design Goal} - 5) \times 2, \text{ in feet.} \qquad (4\text{-}3)$$

Using this trial height, measure the break in line-of-sight B to truck sources.

Example. Refer to Figure 4-14 again. For the same roadway/receiver geometry as in the above example, the task is to determine the barrier dimensions necessary to provide a total attenuation of 8 dB. The first trial Design Goal truck attenuation is then 6 dB, and the trial barrier height is

$$H = 2 + \Delta H, \ \Delta H = (6 - 5) \times 2 = 2 \text{ ft.}$$

Then H is 4 feet, and B is 2 feet since ΔH is approximately equal to B for the geometry at this site.

3.6 Using the values of L/S, B, P, and Δ(truck), use the Barrier Nomograph to determine the necessary subtended angle.

3.7 Using this subtended angle, determine the attenuation for car sources using the appropriate value of B.

Example (continued). For L/S = 200 feet, B = 2 feet, P = 75 feet and Δ(truck) = 6 dB, Figure 4-16 shows the use of the Barrier Nomograph to determine a subtended angle of 170°. Using the angle, and a break in line-of-sight B for cars of 7 feet, the attenuation of cars can be seen to be 9.5 dB (Figure 4-16).

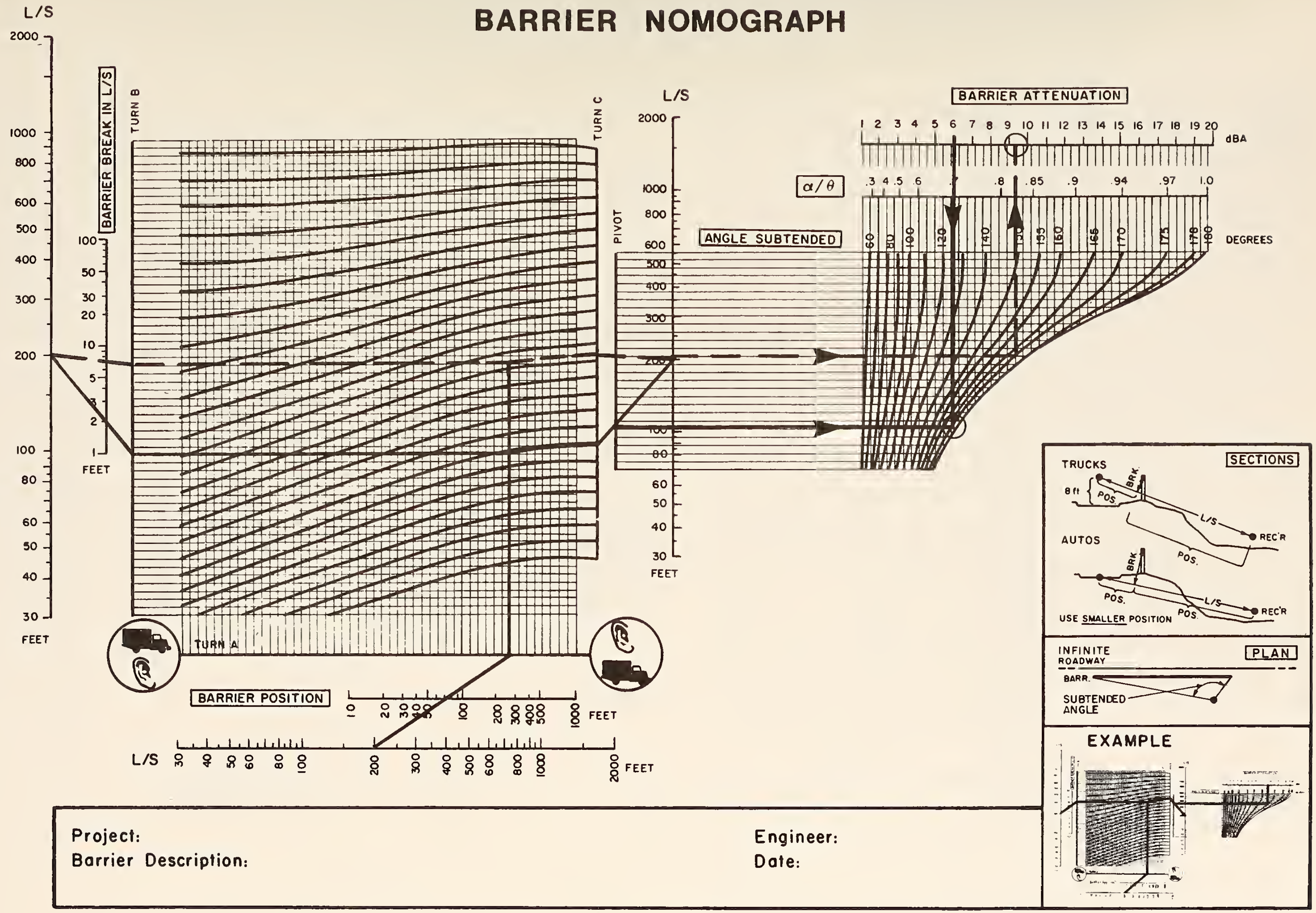


FIGURE 4-16 Use of Nomograph for Trial 4 Foot Barrier.

3.8 Refer to Figure 4-17 to determine the total attenuation resulting from the car and truck attenuations defined above. Since the total attenuation will depend upon the relative contribution of cars and trucks to the total noise level, several curves are given in the figure which correspond to car versus truck contributions ranging from a car-dominated noise exposure (top curve) to a truck-dominated noise exposure (bottom curve). The curves are identified by the difference between car and truck noise levels, L(car) - L(truck), as well as by the approximate truck mix and closest appropriate speed. Using the proper curve and the difference in attenuation for car and truck sources, determine the difference between the total attenuation and the truck attenuation, and thus the total attenuation. If this does not meet the Design Goal, adjust the trial truck attenuation by the incremental difference by which the total attenuation does not meet its design level. Repeat Steps 3.5 through 3.8 until the Design Goals are met.

Example (continued). Assume that there is a 5% truck mix, and the average speed is about 55 mph. Then truck noise levels will exceed car noise levels by approximately 3 dB. Refer to Figure 4-17; from the above example the difference between car d truck attenuation is 9.5 - 6 = 3.5 dB. Using the curve corresponding to L(car) - L(truck) = 3 dB (or truck % = 5 at 55 mph), the difference between the total attenuation and the truck attenuation is about 1 dB. Thus the total attenuation is 6 + 1 = 7 dB, or 1 dB too low; this barrier does not provide the required attenuation.

As a second trial, the new truck attenuation Design Goal becomes 6 dB (from the first trial) plus 1 dB (the amount

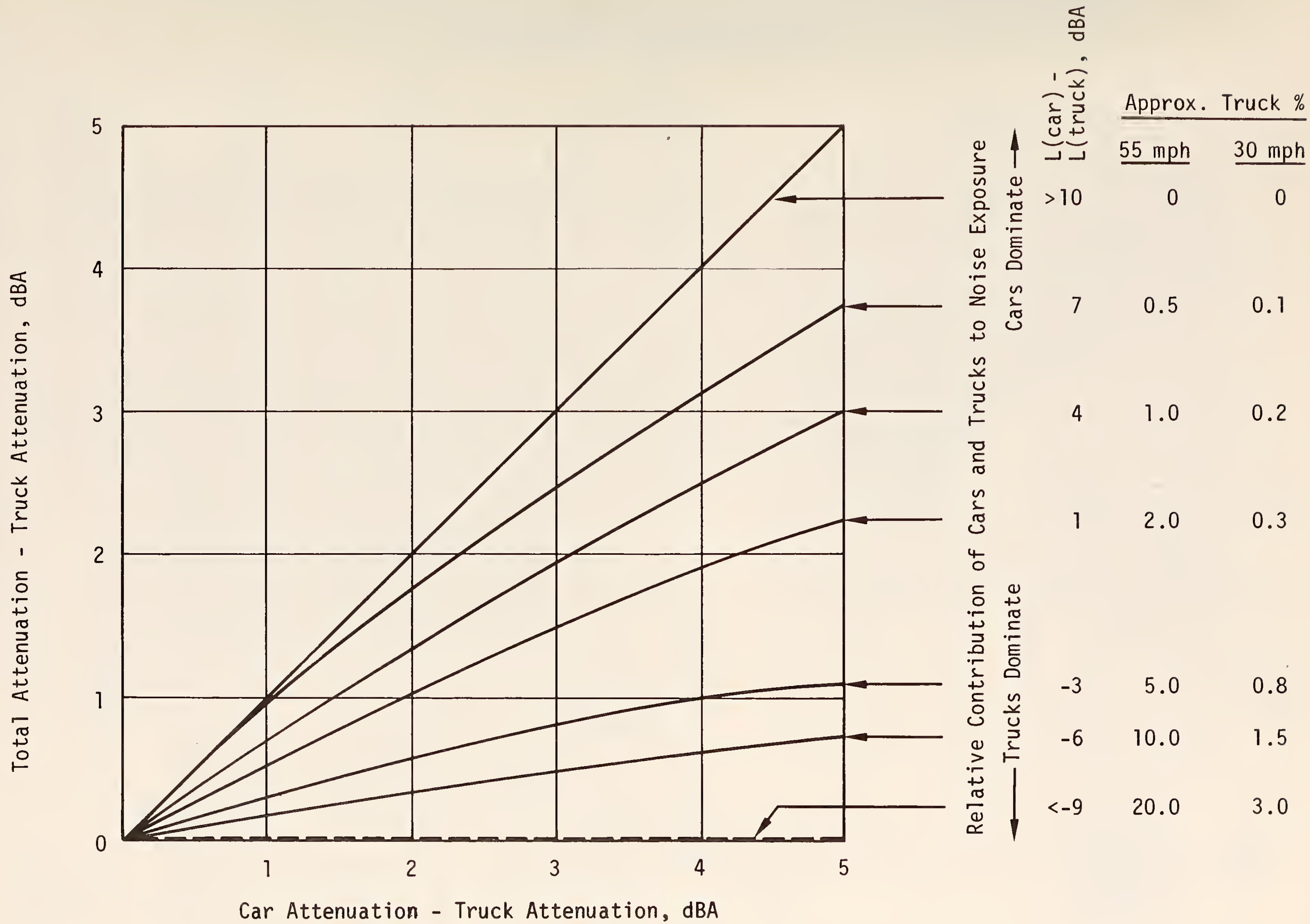


FIGURE 4-17 Total Barrier Attenuation as a Function of Car vs. Truck Attenuation.

by which the first barrier did not meet the Design Goal) or 7 dB. This trial attenuation translates to a new trial barrier height of 6 feet, with B = 4 feet. Figure 4-18 shows that this barrier will provide 7 dB attenuation for trucks if it subtends an angle of 165°. For this angle, the car attenuation (with B = 9 feet) is 9.5 dB.

From Figure 4-17, these attenuations will provide a total attenuation of 8 dB. Thus a barrier 6 feet high, subtending an angle of 165°, will provide the required attenuation. The barrier length is 1900 feet (based on a subtended angle of 165° to a receiver 125 feet behind the barrier).

3.9 Using the attenuation of truck sources determined above, draw a line vertically down from the Barrier Attenuation scale through the Angle Subtended chart. Every point on this line represents a different potential barrier which will provide the same attenuation. For a fixed barrier position, this allows a tradeoff of barrier height versus length.

Based on topographic and community constraints, as well as those constraints defined graphically in the route map prepared in Step 2, define allowable barrier lengths for the selected position. Determine subtended angles for these lengths.

3.10 For each alternative, work backwards using the nomograph to determine the necessary barrier break, and then measure on the cross section map to determine barrier height.

BARRIER NOMOGRAPH

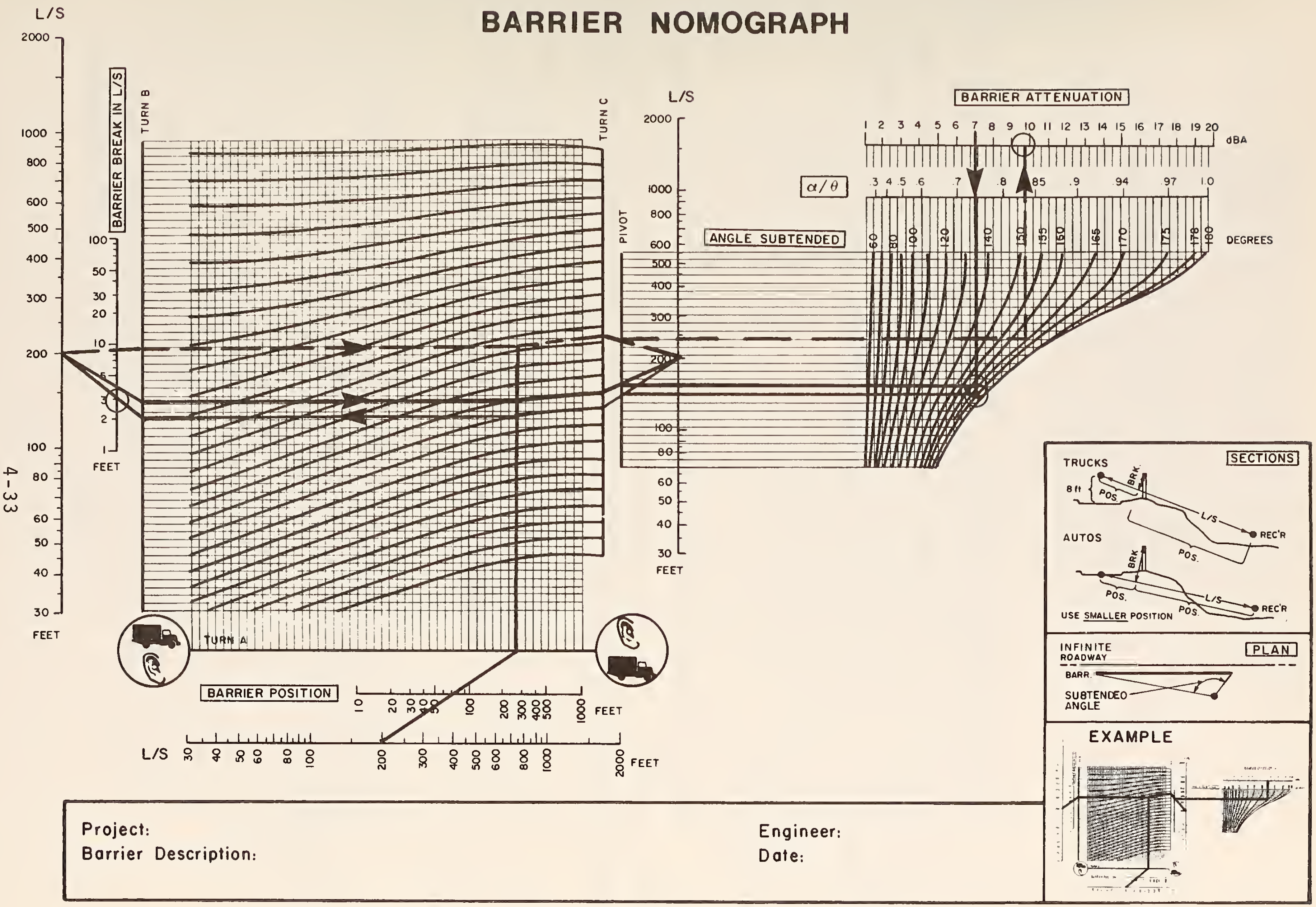


FIGURE 4-18 Use of Nomograph for Trial 6 Foot Barrier.

Example (continued). As shown on Figure 4-18, by continuing the 7 dB truck attenuation line downward from 165° to 170°, another barrier (with break B of 3 feet) can be shown to provide the same attenuation. (This is not unexpected since these are the dimensions of the original barrier used above to illustrate the use of the Barrier Nomograph, Figure 4-15.) Similarly, other barriers could be derived from Figure 4-18.

3.11 Eliminate those alternatives which are clearly impractical. Select the combination of height and length which is the most reasonable for the community. (The total barrier area for each wall option can be determined; the cost of the wall will approximately scale with total area and this may be used as a rough guideline for selecting the most desirable barrier. Also, consider the extent of the community in assessing length requirements.)

3.12 After selection of the desired height and length, compute the attenuation for car sources as described above, and verify using Figure 4-17 that the total attenuation meets Design Goals.

3.13 For this barrier wall, define the necessary parameters for the appropriate farthest critical receiver from the barrier. Use the nomograph to determine attenuation for car and truck sources.

3.14 If the Design Goal for this receiver is not met, modify the height or length as necessary to achieve the desired attenuation.

3.15 If the design of the barrier has been changed, re-evaluate the barrier attenuation for the close-in receiver.

3.16 Evaluate the design for the closest and farthest receivers at each end of the community. Adjust barrier length (by using a section that bends back if necessary) to provide sufficient subtended angle.

3.17 Steps 3.3 to 3.16 have resulted in a barrier design located close to the roadway which will satisfy design requirements. If right-of-way availability and topographic features permit, it would be desirable to determine additional barrier locations and designs. Wherever possible, at least two other locations should be examined, a position as far from the highway as possible, and a position midway. Review the topography between the roadway and the receivers. Attempt to take advantage of land forms which rise above average terrain to minimize the height of wall necessary for construction.

3.18 For each newly selected location determine L/S and P and perform the above analysis from Step 3.5 to yield additional designs.

4-4 Step 4: Identify Additional Barrier Treatments

In Step 5, specific materials and structural designs will be selected for each of the geometrical alternatives defined in Step 3. Depending upon local site and community conditions, however, various barrier "treatments" may be required. These treatments may refer to the application of materials onto the barrier, or the incorporation of design features within the barrier itself. In order to incorporate the selection of these treatments into the barrier design process in Step 5, this step identifies those conditions under which these treatments will be needed.

4.1 Consider the need for treatments to improve the weathering properties of the barrier. Among the factors to be considered include knowledge of the weather conditions that might occur at the site, previous maintenance experience in the area, and the requirements for cleaning the barrier on either the highway or community side.

4.2 Consider the need for aesthetic treatments, based on community attitudes and preferences, neighborhood characteristics, and other local conditions.

4.3 If vertical barriers are to be constructed on both sides of the highway, determine the need for applying acoustically absorptive material on the highway side of the barrier, according to the following. If double barriers are not to be used, this step as well as Step 4.4 may be skipped. (Note that the following methodology is applicable to any vertical walls on both sides of the highway, such as a barrier wall on one side and a high retaining wall on the other, or the vertical walls on each side of a deep cut section.)

<u>4.3.1</u> Prepare a cross-section map of the roadway at its closest point to the nearest critical receiver. Include the location and height of both barriers and the critical receiver location.* Indicate on the cross-section map the values of the following parameters (refer to the lower left corner of Figure 4-19 for a sample sketch): the separation between barriers, W, in feet;

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*If several sets of parallel barrier alternatives are under consideration, perform this analysis using the barriers closest to the roadway, that is, those barriers with smallest separation between them.

PARALLEL BARRIER NOMOGRAPH

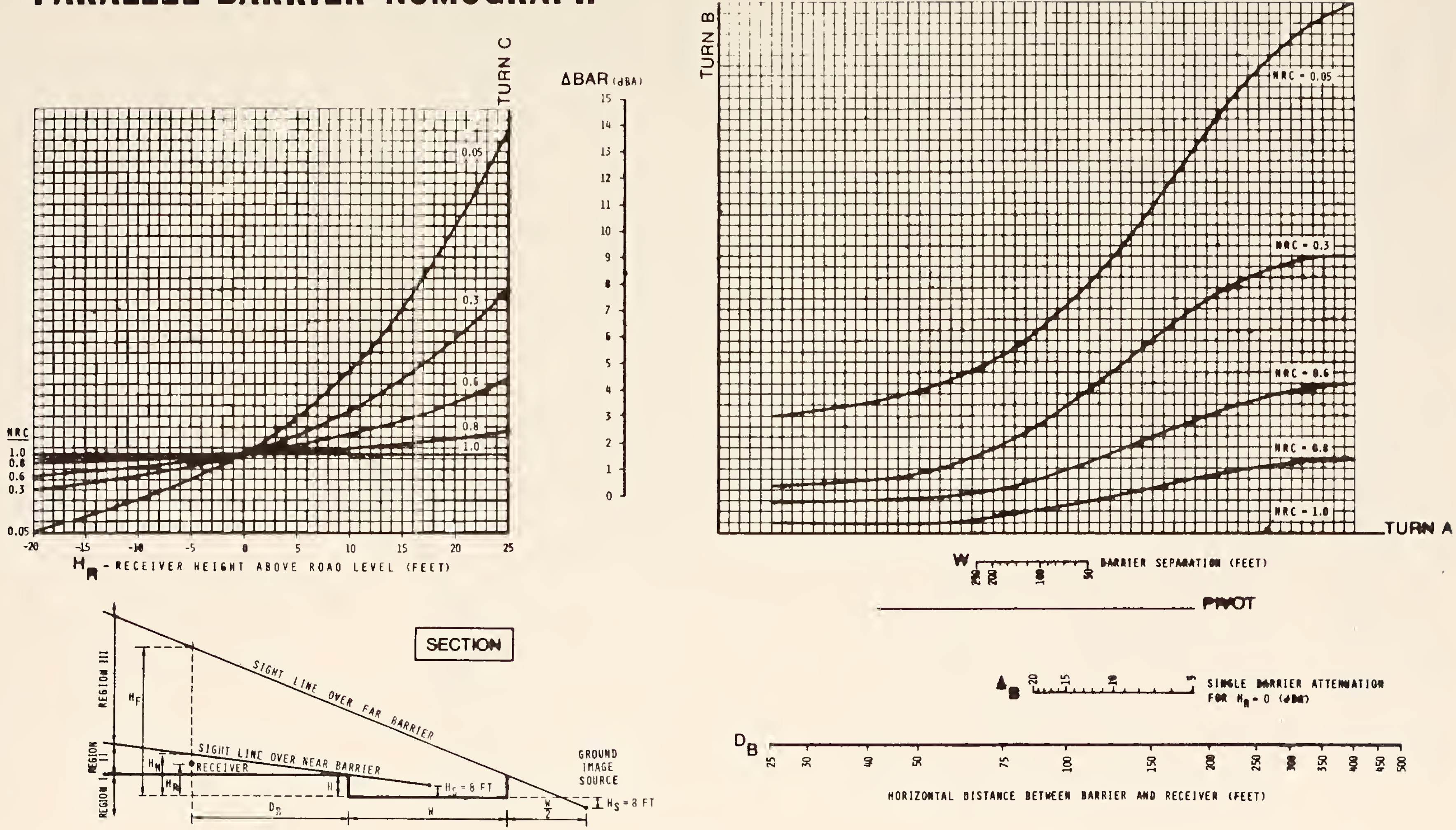


FIGURE 4-19 Nomograph for Determining the Effects of Parallel Barriers

the barrier height, H, in feet; the horizontal distance from barrier to receiver, D_B, in feet; and the receiver height above road level, H_R, in feet.

<u>4.3.2</u> As shown in the figure, locate the noise source at the center of the roadway eight feet above ground level. Draw the sight line from this source over the <u>near</u> barrier; label the height above road level at which this sight line intersects the receiver location as H_N.

<u>4.3.3</u> As shown in the figure, locate the first ground image source eight feet below road level at a distance $\frac{W}{2}$ from the <u>far</u> barrier. Draw the sight line from this source over the top of the far barrier until it intersects the receiver location. Label the height above road level of this intersection as H_F.

<u>4.3.4</u> Determine H_N and H_F by measurement and indicate on the drawing.

<u>4.3.5</u> Determine the region in which the receiver is located: if H_R is less than H, the receiver is in Region I. If H_R is greater than H but less than H_N the receiver is in Region II. If H_R is greater than H_N, the receiver is in Region III. Proceed as follows for receivers in Regions I or II; skip to Step 4.3.9 for receivers in Region III.

Example. Figure 4-20 shows a section through a highway with parallel barriers, indicating values of the following parameters: W = 116 feet, D_B = 112 feet and H = 16 feet. By measurement the values of H_N and H_F are determined to be 30 feet and 116 feet respectively.

4.3.6 Using the Barrier Nomograph (Figure 4-13), determine the attenuation provided by the near barrier for the eight foot source in the center of the road for two heights: the actual receiver height, and the height corresponding to roadway level (i.e., $H_R = 0$).

4.3.7 The degradation in barrier performance ΔBAR may be determined using the nomograph in Figure 4-19.

4.3.7.1 Starting at the lower right corner of the figure, draw a straight line between the D_B and W scales.

4.3.7.2 Draw a straight line from the Δ_B scale for the barrier attenuation corresponding to a receiver height of zero feet above road level, through the intersection of the first line with the pivot line, and continue to Turn A.

4.3.7.3 Project this line vertically upward to the curve labeled NRC = 0.05, which corresponds to a nearly perfect reflecting surface. Turn left and project horizontally to Turn B.

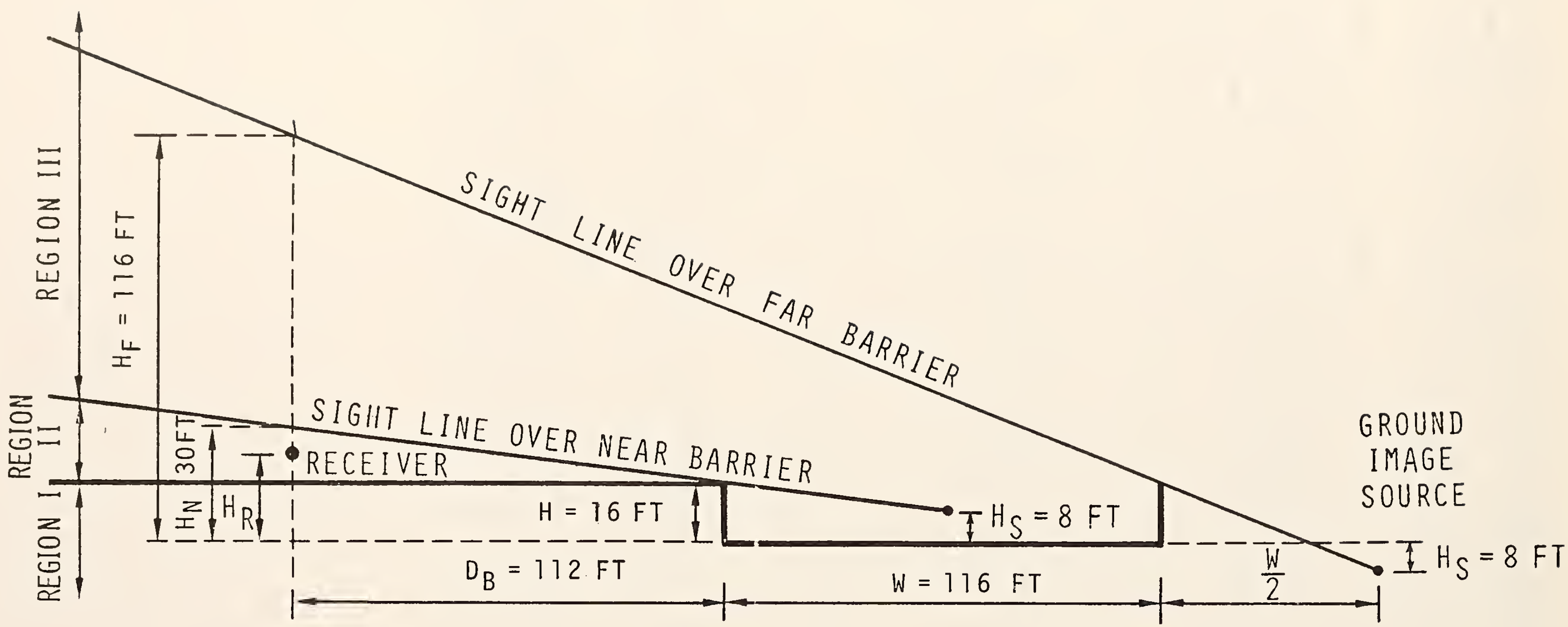


FIGURE 4-20 Example of Cross Section Through Parallel Barrier Configuration.

4.3.7.4 If the receiver is located in Region I proceed as follows. If the receiver is located in Region II skip to 4.3.7.8.

4.3.7.5 Refer to the grid on the left of the figure. Project upwards vertically from the H_R scale to the curve labeled NRC = 0.05. Turn right and project horizontally to Turn C.

4.3.7.6 Draw a straight line between the points determined on the Turn B and Turn C lines.

4.3.7.7 Read the value of ΔBAR where this line crosses the center scale. This value is the barrier degradation for a receiver height H_R. Skip to Step 4.3.8.

Example (continued). For a receiver height of 5 feet, the receiver is in Region I. The Barrier Nomograph is used to determine the attenuation from the near barrier, using L/S = 170 feet, P = 58 feet, B = 10 feet for H_R = 0, and B = 9 feet for H_R = 5. From the nomograph, the attenuation is 12.5 dB and 11.5 dB for 0 and 5 foot high receivers, respectively. The steps involved in determining ΔBAR are shown in Figure 4-21, numbered sequentially (solid line). For the 5 foot receiver, ΔBAR is 4.5 dB.

4.3.7.8 Refer to the grid on the left of the figure. For a receiver in Region II use the barrier height H as the value of H_R; project vertically upwards from the H_R scale to the curve labeled NRC = 0.05. Turn right and project horizontally to Turn C.

PARALLEL BARRIER NOMOGRAPH

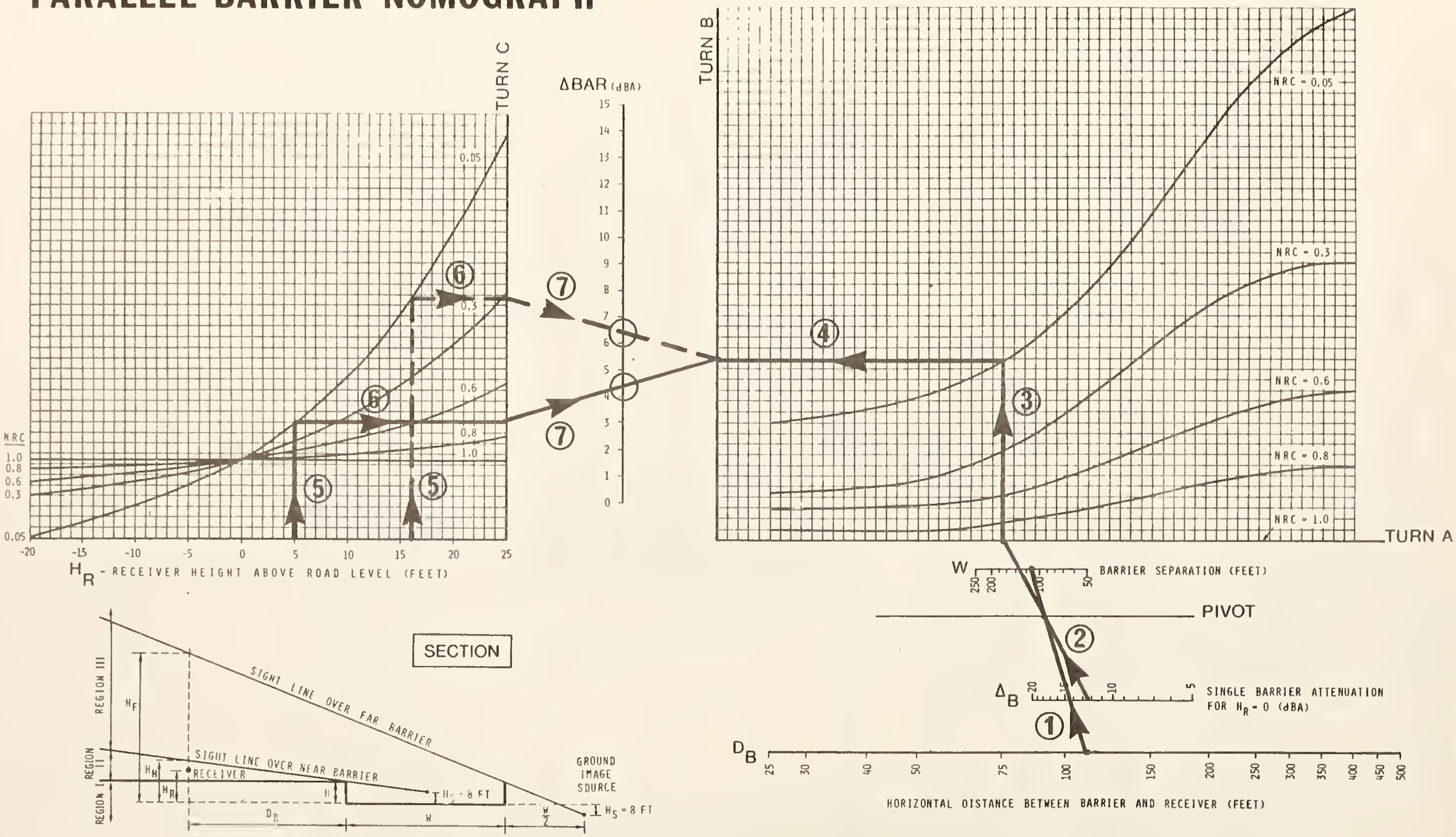


FIGURE 4-21 Use of the Parallel Barrier Nomograph.

4.3.7.9 Draw a straight line between the points determined on the Turn B and Turn C lines.

4.3.7.10 Read the value of ΔBAR where this line crosses the center scale. For a receiver in Region II, the barrier degradation is less than or equal to this value read from the nomograph for a receiver height equal to the height of the barrier H.

4.3.7.11 To determine the barrier degradation for the actual receiver height, construct a graph of ΔBAR versus H_R using the grid provided in Figure 4-22. Plot the following two points: H_R = H, ΔBAR = the value determined above in 4.3.7.10; and H_R = H_F, ΔBAR = 0. Draw a straight line between these two points. Read ΔBAR from the graph corresponding to the actual value of H_R.

Example (continued). For a receiver located 25 feet above road level (therefore in Region II), ΔBAR is first determined for a receiver height equal to barrier height, 16 feet. These steps are shown in Figure 4-21 (dashed line), resulting in ΔBAR = 6.5 dB. In Figure 4-23, the values H_F = 116, ΔBAR = 0, and H = 16, ΔBAR = 6.5 are plotted. The value of ΔBAR for H_R = 25 is read from the graph as 6 dB.

<u>4.3.8</u> In Step 4.3.7, the degradation in barrier performance relative to receivers in Regions I and II for truck sources was determined. Determine the noise reduction for the barrier for truck sources by subtracting ΔBAR from the barrier attenuation for trucks, determined in Step 4.3.6 for the actual receiver height:

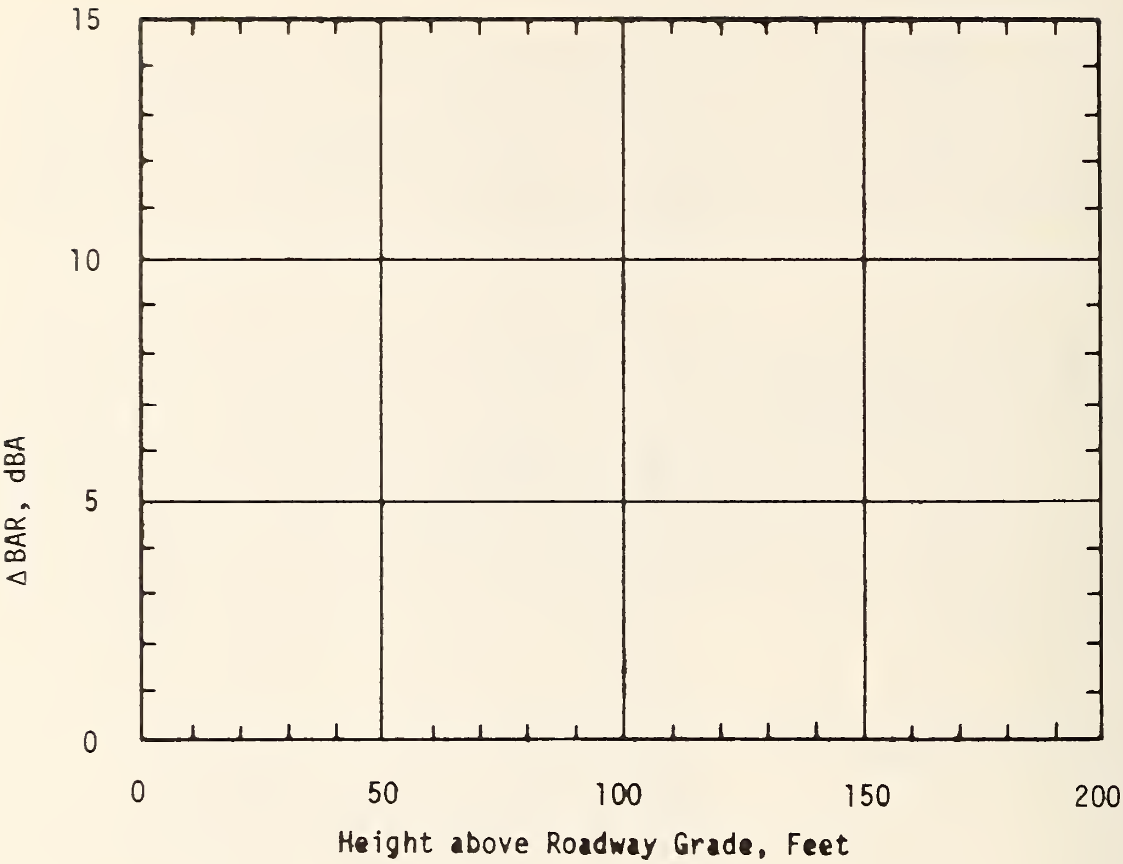


FIGURE 4-22 Grid to Determine ΔBAR for Receivers in Region II.

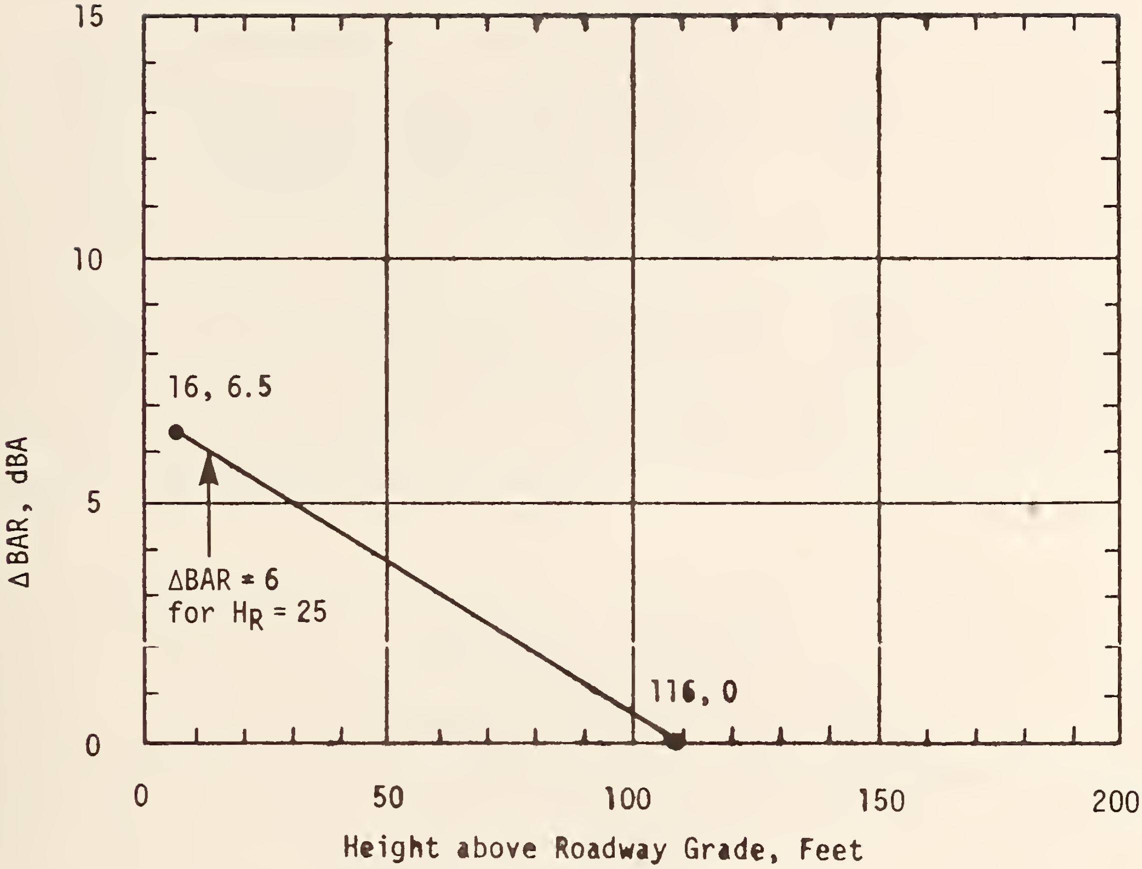


FIGURE 4-23 Use of Grid to Determine ΔBAR.

$$NR = \Delta_B(\text{trucks}) - \Delta BAR(\text{trucks}) \qquad (4\text{-}4)$$

To a first approximation, this noise reduction is appropriate to cars as well as trucks, and therefore is the net noise reduction for the barrier.

Example (continued). For the 5 foot receiver, the near barrier truck attenuation is 11.5 dB. Thus, the net noise reduction for both cars and trucks is 11.5 - 4.5 = 7 dB.

4.3.9 In Region III, the receiver has a clear view of the highway, and the near barrier thus provides little or no attenuation. The maximum effect of the double walls will be to increase the unshielded level at the receiver by 3 dB. This effect decreases to 0 at a height H_F.

4.4 The effects of the double wall configuration can be reduced (or eliminated entirely) by increasing barrier height (and thereby increasing the attenuation) and/or by decreasing the reflected sound levels by applying absorptive treatments to the wall surfaces. If ΔBAR is within 3 dB, increasing wall height may be the most practical approach. For higher degradations the use of absorptive materials may be more desirable.

4.4.1 If an increase in barrier height is considered, note that ΔBAR will increase as Δ_B increases (but not as rapidly). Choose a barrier height to give an additional attenuation somewhat greater than ΔBAR. Determine the actual barrier attenuation using the Barrier Nomograph (Figure 4-13) and then re-evaluate ΔBAR with the Parallel Barrier Nomograph (Figure 4-19) to verify that the net noise reduction meets Design Goals.

4.4.2 If it is desired to use absorptive treatments, the acoustical benefits can be determined as a function of the noise reduction coefficient, NRC. The absorptive materials presented in later steps have NRC values of 0.5 or better. To judge the benefits of using such materials, re-evaluate the degradation of barrier performance ΔBAR using Figure 4-19 for various noise reduction coefficients. (Note that ΔBAR = 0 for NRC = 1.0) Figure 4-24 indicates the improvement in Region III. Determine the minimum NRC which would reduce ΔBAR to within desirable limits.

Example (continued). Figure 4-25 shows the benefits of using absorptive treatments having NRC values on the order of 0.8. For both the 5 foot (Region I) and 25 foot (Region II) receivers, ΔBAR is reduced to within 0.5 dB. For a receiver in Region III, the increase in unshielded level is also within 0.5 dB.

4.5 If the noise barrier is to be located within 30 feet of the traveled way, a safety barrier may be appropriate. Such a barrier could be placed in front of the wall, or integrated within the wall construction itself. Consideration should be given to local requirements dealing with safety, and to previous experience and accident records for similar configurations and for the particular roadway site under consideration.

FIGURE 4-24 EFFECTS OF BARRIER REFLECTIONS FOR RECEIVERS IN REGION III ($H_N < H_R < H_F$)

NRC	Increase in Unshielded Level, dBA
0.05	3.0
0.1	2.5
0.3	1.5
0.6	1.0
0.8	0.5
1.0	0.0

PARALLEL BARRIER NOMOGRAPH

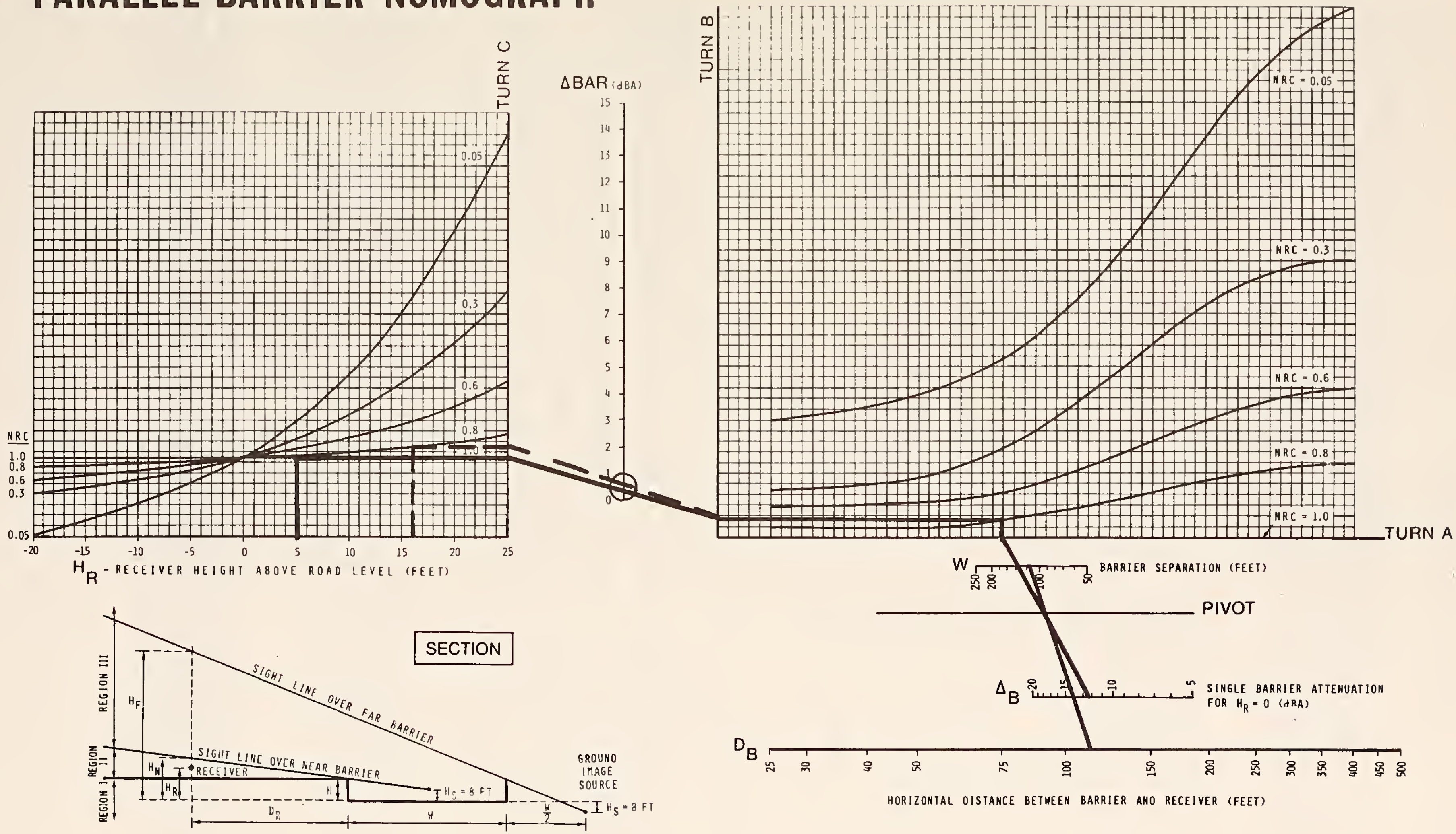


FIGURE 4-25 Use of Nomograph to Determine Benefits of Absorptive Treatments.

In Step 3, alternative barrier locations were selected, and the necessary height and length of the barrier determined for each of these alternatives. In this step, specific design options are selected for each barrier location.

5.1 Refer to the Design Option Worksheet (Figure 4-26.) The first column labeled "Material" is to be used to identify the basic material of which the barrier might be constructed. Each of the next columns is to be used for a single geometrical alternative. Fill in the three basic dimensions for each alternative in the column heading: the barrier position P_R represented by the distance from the barrier to the edge of the roadway; the barrier height H; and the barrier length L. Each row of the Worksheet then corresponds to one or more specific barrier designs using a particular material for at least one of the alternative locations.

5.2 Among those materials commonly used for noise barrier walls are concrete, masonry block, steel, and wood. Earth berms are also used either alone or in combination with one of the above barrier walls. Appendices A and B provide reference drawings with design details for each of these materials. Select appropriate materials* for potential use. List the materials in the left column of the Worksheet.

5.3 If it is desirable to consider other materials for construction, Figure 4-27 provides a more comprehensive listing of potential barrier materials (including materials used in

*Note that with the exception of the wood barriers, all the barriers included in the reference drawings have transmission losses of 25 dB or better. Depending on the wood used, the TL of the wood barrier would be in the range from 22 to 26 dB.

FIGURE 4-26

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 / /	No. 2 / /	No. 3 / /

Wind Loading __________ Safety Barrier __________

Aesthetics __________ Absorption __________

Weathering __________ Other Comments __________

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?

FIGURE 4-27

MATERIALS FOR USE IN OUTDOOR BARRIERS

MATERIAL	THICKNESS, INCHES	TRANSMISSION LOSS, dBA[1]	COST FACTOR, PER SQUARE FOOT[2]	COMMENTS
Wood				
Fir	1/2	17	.68	Tongue and groove boards recommended to avoid leaks (for fir, pine, redwood, cedar)
	1	20	.75	
	2	24	1.37	
Pine	1/2	16	.77	
	1	19	[illegible]	
	2	23	[illegible]	
Redwood	1/2	16	[illegible]	
	1	[illegible]	.76	
	2	23	1.37	
Cedar	1/2	15	[illegible]	
	1	18	.76	
	2	22	1.37	
Plywood	1/2	20	.44	
	1	23	.70	
Particle Board	1/2	20	.39	Should be water resistant treated

FIGURE 4-27 (cont'd)

MATERIALS FOR USE IN BARRIER DESIGNS

MATERIAL	THICKNESS, INCHES	TRANSMISSION LOSS, dBA[1]	COST FACTOR, PER SQUARE FOOT[2]	COMMENTS
Metals				
Aluminum	1/16	23	5.02-6.40	May require treatment to reduce glare (for aluminum, steel)
	1/8	25	8.40-10.80	
	1/4	27	12.80-16.70	
Steel	24 ga	18	2.23-2.75	
	20 ga	22	2.31-2.91	
	16 ga	15	2.43-3.11	
Lead	1/16	28	[illegible]	
Concrete, Masonry, etc.				
Light Concrete	4	36	5.20	
	6	39	5.60	
Dense Concrete	4	40	5.10	
Concrete Block	4	32	2.00	
	6	36	2.25	
Cinder Block (Hollow Core)	6	28	2.40	

FIGURE 4-27 (cont'd)

MATERIALS FOR USE IN BARRIER DESIGNS

MATERIAL	THICKNESS, INCHES	TRANSMISSION LOSS, dBA[1]	COST FACTOR, PER SQUARE FOOT[2]	COMMENTS
Concrete, Masonry, etc. (cont'd)				
Brick	4	33	5.76	
Granite	4	40	15.40-19.40	
Composites				
Aluminum Faced Plywood	3/4	21-23	3.22	Aluminum is .010 inch thick. Special care necessary to avoid delaminations (for all composites)
Aluminum Faced Particle Board	3/4	21-23	3.00	
Plastic Lamina on Plywood	3/4	21-23	3.60	
Plastic Lamina on Particle Board	3/4	21-23	3.20	
Miscellaneous				
Glass (Safety Glass)	1/8	22	5.60	
	1/4	26	8.48	

FIGURE 4-27 (cont'd)

MATERIALS FOR USE IN BARRIER DESIGNS

MATERIAL	THICKNESS, INCHES	TRANSMISSION LOSS, dBA[1]	COST FACTOR, PER SQUARE FOOT[2]	COMMENTS
Miscellaneous (cont'd)				
Plexiglass (Shatterproof)		22-25	12.63	
Masonite	1/2	20	1.20	
Fiberglass/ Resin	1/8	20	4.50	
Stucco on Metal Lath	1	32	1.05	
Polyester with Aggregate Surface	3	20-30	3.80-5.20	TL depends on surface density of the aggregate

Notes:

[1] A-weighted TL based on generalized truck spectrum

[2] Cost factors based on materials alone, without structural support. For concrete and masonry, cost factor is for free standing wall. For glass, plexiglass and fiberglass, cost of aluminum frame is included.

the reference drawings). In selecting additional materials from this list, consideration must be given to transmission loss characteristics; the transmission loss of each material is shown in the figure. Note that some materials (and especially wood materials) are prone to develop openings or gaps in the barrier through weathering. The effect of openings on the TL of the barrier can be determined from Figure 4-28, which has been developed for wood materials. (For other materials, use the curve with the closest TL for 0% open area.)

5.4 Figure 4-29 indicates the noise reduction resulting from use of a material as a function of its transmission loss (based on the physical properties of the material as well as the presence of openings) and the attenuation if there were no transmission through the barrier. For each material considered, compare the transmission loss determined from Figures 4-27 and 4-28 with the attenuation for the barrier (determined in Step 3) to evaluate the maximum noise reduction achievable. Eliminate from further consideration those materials which would seriously degrade barrier performance by transmission through the barrier. List acceptable materials on the Worksheet.

Example. Consider the use of one-half versus two inch tongue and groove fir boards for a proposed barrier. Figure 4-27 indicates TL values of 17 and 24 dB, respectively. If the barrier has been designed to provide an attenuation of 10 dB, Figure 4-29 shows that use of one-half inch fir will result in a noise reduction of about 9 dB, while two inch fir will result in a noise reduction of nearly 10 dB. In this case the factor of two in cost to use two inch rather than one-half inch boards may not be justified.

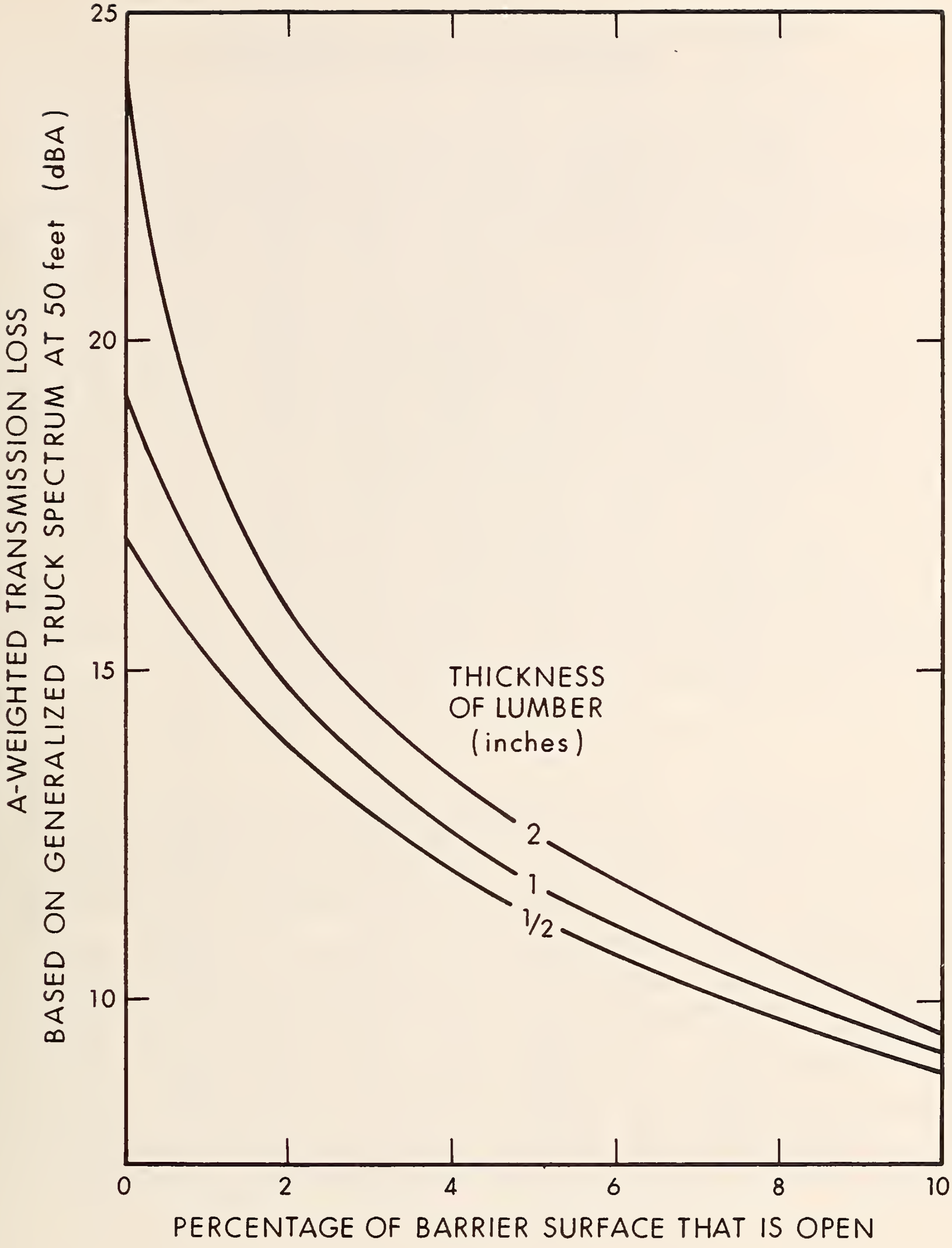


FIGURE 4-28 Effect of Barrier Openings on TL.

FIGURE 4-29 NOISE REDUCTION OF A BARRIER AS A FUNCTION OF ITS TRANSMISSION LOSS

Attenuation, dB	TRANSMISSION LOSS, dB				
	10	15	20	25	30
5	3.8	4.6	4.9	5.0	5.0
6	4.5	5.5	5.8	6.0	6.0
7	5.2	6.4	6.8	6.9	7.0
8	5.9	7.2	7.7	7.9	8.0
9	6.5	8.0	8.7	8.9	9.0
10	7.0	8.8	9.6	9.9	10.0
11	7.5	9.5	10.5	10.8	11.0
12	7.9	10.2	11.4	11.8	11.9
13	8.2	10.9	12.2	12.7	12.9
14	8.5	11.5	13.0	13.7	13.9
15	8.8	12.0	13.8	14.6	14.9
16	9.0	12.5	14.5	15.5	15.8
17	9.2	12.9	15.2	16.7	16.8
18	9.4	13.2	15.9	17.2	17.7
19	9.5	13.5	16.5	18.0	18.7
20	9.6	13.8	17.0	18.8	19.6

However, if the barrier has been designed to provide 15 dB attenuation because of more stringent noise reduction goals, Figure 4-29 shows noise reductions of about 12.5 and 14.5 dB for one-half inch and two inch boards respectively. In this case the one-half inch boards degrade barrier performance by 2.5 dB, which may not be an acceptable situation.

Assume that with time a 2% open area will develop if tongue and groove boards are not used in the construction of the barrier. Figure 4-28 shows that the TL values are reduced to 14 and 16 dB for the one-half inch and two inch boards, respectively. Figure 4-29 indicates a compromise in barrier performance of about 1 dB for a barrier designed for 10 dB attenuation, and 3 dB for a barrier designed for 15 dB attenuation. This illustrates that (1) openings can seriously degrade a barrier's potential for noise reduction, and (2) openings tend to equalize the TL of different thickness materials, so that if an opening cannot be avoided there is little acoustical benefit in using a heavier material.

5.5 The Design Option Worksheet may be considered as a matrix of possible barrier designs. If a barrier could be constructed from each of the materials listed in the first column for each of the barrier locations, then the number of possible barrier designs would be the number of locations times the number of materials, assuming only one specific design per material. If it is desirable to evaluate more than one design for a particular material, then the number of potential designs would increase accordingly. At this point it would be appropriate to eliminate those designs which could not be constructed at one of the alternative locations. The primary reason that this might happen would be the amount of land required for the construction of an earth berm. Figure 4-30 indicates the width required for different height earth berms as a function of the slope. This table can be used to eliminate those locations which would not accommodate earth berms, if this type of barrier is one of the designs under consideration. Eliminate other material/ location options which are impractical.

5.6 In addition to the basic construction details shown in the reference drawings in Appendices A and B, for each material several "additional treatments" are detailed. These treatments may be used to upgrade the weathering properties of the barrier, improve the visual appearance of the barrier, or provide sound absorption. The weathering/ aesthetic treatments are detailed on the reference drawings for the particular barrier for which they apply; the absorption treatments are detailed separately in Appendix C. Figure 4-31 provides an index to the various treatments. Note that under the broad category of "treatment" is included such diverse items as painting, use of different types of masonry blocks, application of stucco, wood or sheet metal facings, and landscaping.

5.7 Each complete barrier design will include a basic barrier construction using a particular material; weathering/aesthetic treatments if appropriate; a safety barrier if warranted; and absorption treatments if necessary. For ease of tabulation

FIGURE 4-30

APPROXIMATE RIGHT-OF-WAY NECESSARY FOR BERM CONSTRUCTION

	Berm Height			
% of Slope	5	10	15	20
4:1	52'	92'	132'	172'
3:1	42'	72'	102'	132'
2:1	32'	52'	72'	92'

FIGURE 4-31

INDEX TO REFERENCE DRAWINGS

	Design Code	Page Number
Appendix A		
Concrete	C-	C-1,2
Exposed Aggregate	1*	C-3
Sandblast	2*	C-3
Board Form	3*	C-3
Wood Form	4*	C-3
Reinforcing Bar	5*	C-3
Rubber Mat	6*	C-3
Bomanite	7*	C-3
Integral Color	8	C-3
Paint	9*	C-3
Masonry	M-	M-1,2
Vertical Scored	1	M-3
6" Slump	2	M-4
4" Slump	3	M-4
Combed	4	M-4
Split Face	5	M-4
Integral Color	6	M-3,M-4
Paint	7*	M-3,M-4
Steel	S-	S-1
Sheet Metal Trim	1*	S-2
Sheet Metal Trim and Wood	2*	S-3
Sheet Metal Trim and Stucco	3*	S-4
Paint	4*	S-1
Weathering Steel	5	S-1
Wood	W-	W-1
Plywood Facing	1*	W-2
Wood Battens	2*	W-3
Preservative Treatment	3	W-1
Paint	4*	W-1,2
Stain	5*	W-1,2
Earth Berm		
2:1 Slope	B(2)-	B-1
3:1 Slope	B(3)-	B-1
4:1 Slope	B(4)-	B-1
Landscape	1	B-1

FIGURE 4-31

INDEX TO REFERENCE DRAWINGS (cont'd)

	Design Code	Page Number
Appendix B		
Elevated Steel Barrier	ES-	ES-1
Paint	1*	ES-1
Weathering Steel	2	ES-1
Elevated Wood Barrier	EW-	EW-1
Preservative Treatment	1	EW-1
Paint	2*	EW-1
Stain	3*	EW-1
Appendix C		
Absorption Treatments		
Resonant Cavity Blocks	a1	A-1
Paint	(1)*	A-1
Wood Fiber Planks	a2	A-2
Vermiculite Aggregate	a3	A-3
Glass Fiber/Wood Facing	a4	A-4
Paint	(1)	A-4
Glass Fiber/Metal Siding	a5	A-5
Paint	(1)	A-5
Weathering Steel	(2)	A-5
Glass Fiber/Wood on Steel Barrier	a6	A-6
Glass Fiber/Metal on Steel Barrier	a7	A-7

*These treatments are applied to one side only. If application on both sides is desired, use Code twice.

and evaluation, each barrier design will be represented by a barrier "Design Code," with descriptors corresponding to the various constructions and treatments included in the complete design. The Design Code will have four components separated by hyphens, as follows: X - i,i,i - S - aj(i). Each component corresponds to one of the components of the barrier design: the X refers to the basic material used to construct the barrier; the i's refer to various weathering/ aesthetic treatments; the S refers to the use of a safety barrier; and the aj refers to a specific absorption treatment (with additional treatments represented by the (i) following the aj). Figure 4-32 provides further details concerning the Design Code format. The various Design Code components are defined in the reference drawing index, Figure 4-31.

5.8 Review the reference drawings for each of the basic barrier materials under consideration, and select appropriate treatments for each. For barrier materials not included in the reference drawings, develop corresponding treatments as necessary to meet local conditions (and devise appropriate design codes).

5.9 For each empty cell in the location alternatives/materials matrix on the Design Option Worksheet, develop complete designs and enter the Design Codes as appropriate. At the bottom of the Worksheet, provide a brief narrative description of each unique design.

5.10 Note on the bottom of the Worksheet those designs which do not provide the Design Goal Noise Reduction. This will occur if (a) the height and/or length of the barrier are not large enough to provide the necessary attenuation; (b) the

FIGURE 4-32 Design Code Format.

X - i, i, i, - S - aj (i)

BASIC MATERIAL

C for concrete
M for masonry
S for steel
W for wood
B(2) for berm, 2:1 slope
B(3) for berm, 3:1 slope
B(4) for berm, 4:1 slope

See Appendix A for the above.

ES for elevated structure/steel

ES for elevated structure/wood

See Appendix B for the above.

WEATHER/AESTHETIC TREATMENTS

"i" is number referring to additional treatment detailed in Appendix A or B.

If treatment is to be applied to both sides of barrier, use number twice.

SAFETY BARRIER

Use if a crash barrier is to be included in the design.

ABSORPTION TREATMENT

"j" is number referring to specific absorption treatment, detailed in Appendix C.

If additional treatments are to be applied for weather/aesthetic purposes, "i" refers to the treatment number transmission loss of the barrier material is not high enough; (c) the absorptive properties of the barrier surface are not sufficient to reduce reflections from a double wall configuration.

Example. Figure 4-33 shows a completed Design Option Worksheet. Barrier designs are listed for three locations: 15, 60 and 100 feet from the roadway. The barrier dimensions at each location have been selected to provide the required noise reduction. Barrier designs are shown for concrete, masonry and wood materials, and for earth berm configurations. Note that because of space requirements, a berm is only possible at Location 2. Also note that designs are given for a berm alone, and for a berm/wall combination. For all barriers at Location 1, a safety barrier has been included in the design.

4-6 Step 6: Define Cost Factors

6.1 Refer to the Cost Factor Worksheet, Figure 4-34. Enter in the first column each design code listed on the Design Option Worksheet (that is, each filled-in cell on the Design Option Worksheet will have a separate listing on this Worksheet). Also enter the wind loading requirements on top of the Worksheet.

6.2 Enter in the next three columns the location alternative number and the corresponding height and length of each barrier design.

6.3 Cost factors are to be entered in each of the next four columns, corresponding to the cost of the basic construction, the weathering and aesthetic treatments, the construction of a safety barrier where necessary, and the use of absorptive linings where necessary. For each letter or numeral in the design code, a separate cost factor should be listed.

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 15 / 13 / 7000	No. 2 60 / 18 / 6000	No. 3 100 / 15 / 8000
CONCRETE	C-2,2,8-S	C-2,2,8	C-2,2,8
	C-3,3,8-S	C-3,3,8	C-3,3,8
MASONRY	M-3,6-S	M-3,6	M-3,6
WOOD	W-2,2,3-S	W-2,2,3	W-2,2,3
	W-4,4-S	W-4,4	W-4,4
BERM		B(2)-1	
		B(4)-1; M-3,6	

Wind Loading	30 #/□	Safety Barrier	FOR LOC. No. 1
Aesthetics	YES	Absorption	NO
Weathering	YES	Other Comments	

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED?
C-2,2,8	CONCRETE/SANBLAST/INTEGRAL COLOR	NO
C-3,3,8	CONCRETE/BOARD FORM/INTEGRAL COLOR	NO
M-3,6	MASONRY/4" SLUMP/INTEGRAL COLOR	NO
W-2,2,3	WOOD/BATTENS/PRESERVATIVE	NO
W-4,4	WOOD/PAINT	NO
B(2)-1	2:1 BERM/LANDSCAPE (84' REQ'D)	NO
B(4)-1	4:1 BERM/LANDSCAPE - 10' HIGH (92' REQ'D)	NO
M-3,6	MASONRY/4" SLUMP/INT. COLOR - 8' HIGH	

FIGURE 4-33 Use of Design Option Worksheet

FIGURE 4-34
COST FACTOR WORKSHEET

Wind Loading

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS					TOTAL COST
				Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	

6.3.1 The cost factors are found on the various reference drawings in Appendix A for the basic constructions and weather/ aesthetic treatments (and similarly in Appendix B for barriers on elevated structures), and in Appendix C for absorption treatments. For a particular design, the cost factor is a function of height of the barrier, and either the wind loading requirement of the wall or the slope of the earth berm. The correct cost factor is found by first selecting the appropriate wind loading (or slope), and then choosing the proper height. Note that the various letters and numerals of the design code are indicated in block form on the reference drawings just under or above the appropriate cost factor.

> Example. Consider a 15 foot wall designed for 30 pounds per square foot wind loading. The cost factor for design option C-2,2,8 is determined as follows. From the reference drawings for concrete barriers, the cost factor for the 15 foot basic concrete wall designed for 30 pounds per square foot is 88.15. The cost factors for treatments C-2 and C-8 are 3.11 and .35 respectively for 15 foot height. Thus the cost factor for the treatments is 3.11 + 3.11 + .35 = 6.57. The total cost factor for the wall is 6.57 + 88.15 = 94.72.

If a barrier height is used other than 5, 10, 15, or 20 feet the correct cost factor can be found by interpolation between the cost factors for the next lowest and next highest barriers. Figure 4-35 provides a grid for performing this interpolation. On the bottom horizontal axis plot the value of the cost factor for the next lowest wall. Plot the cost factor for the next highest wall on the top axis, and draw a line connecting these two points. The cost factor for the design wall can then be read directly from the graph corresponding to the actual height, as read on the vertical axis.

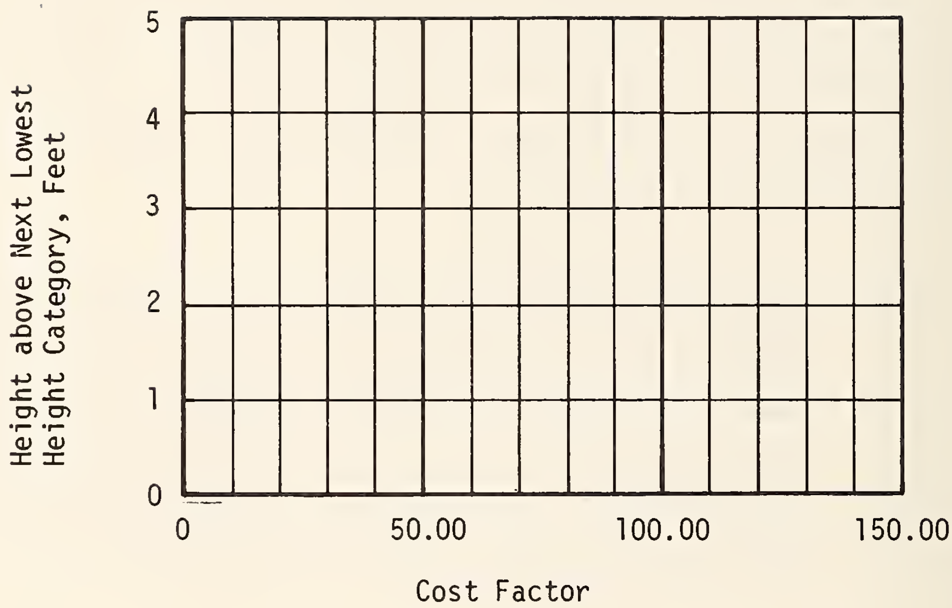


FIGURE 4-35 Grid to Determine Barrier Cost Factor.

Alternatively, the interpolation can be done more precisely as follows. If H and CF represent "height" and "cost factor," respectively, and the subscript + represents the 5-foot height category <u>above</u> the design wall (and - represents the height category <u>below</u> the design wall), then the desired cost factor CF for wall of height H is

$$CF = CF_{+} - \frac{(H_{+} - H) \times (CF_{+} - CF_{-})}{5} \tag{4-5}$$

Example. An 18-foot wooden wall basic cost factor is determined by plotting the 15-foot and 20-foot cost factors, and interpolating, as shown on Figure 4-36. Alternatively, the interpolation may be performed according to equation (4-5):

$$\text{cost factor} = 111.55 - \frac{2 \times (111.55 - 64.69)}{5} = 92.81$$

<u>6.3.2</u> If a safety barrier is included in the design, refer to Figure 4-37 for cost factors for three types of barriers. Select the desired barrier type and enter the corresponding cost factor.

<u>6.3.3</u> For barrier designs based on the materials listed in Figure 4-27, cost factors are provided on a square foot basis. Note that the cost factors refer to the wall material only, and do not include the costs of structural support (except for the concrete and masonry materials). Cost estimates for the total wall construction should be developed using the wall material costs in Figure 4-27.

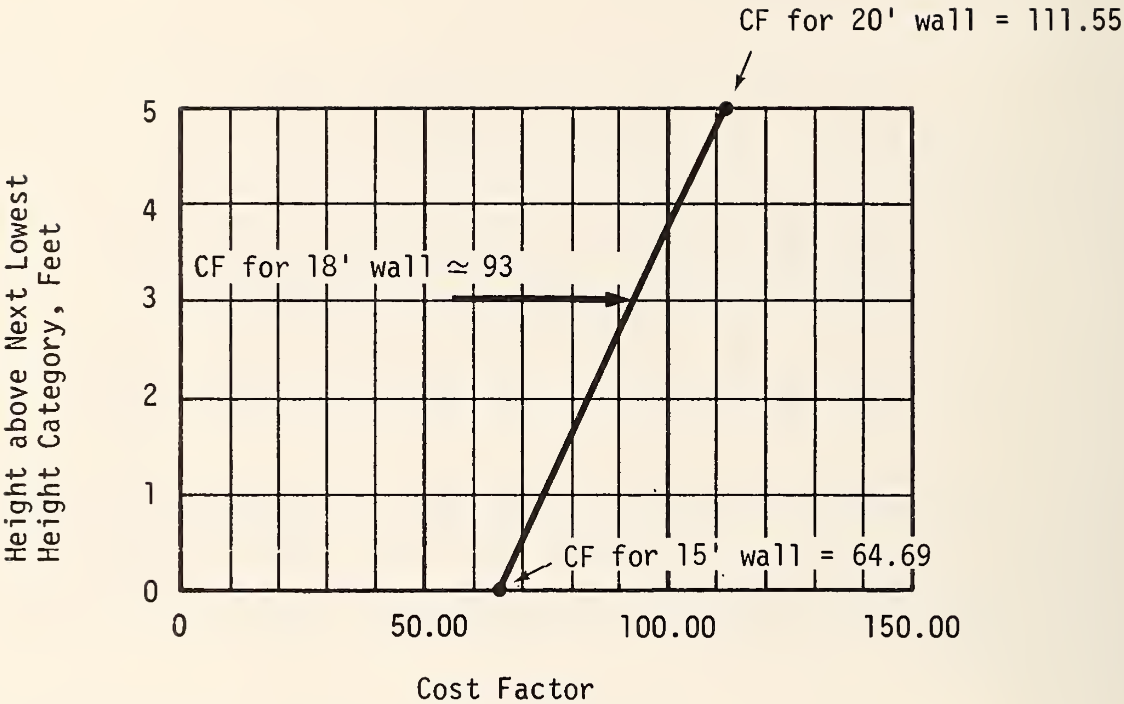


FIGURE 4-36 Use of Grid to Determine Cost Factor.

FIGURE 4-37 SAFETY BARRIER COST FACTORS

Barrier Type	Cost Factor
Cable*	4.80
Metal Beam	19.97
Concrete	12.08

*Not recommended for roadway-to-barrier distances less than sixteen (16) feet.

Source: Based on data in Reference 4-3.

6.4 Sum the individual cost factors and enter the total in the next column, for each barrier design.

6.5 Refer to Figure 4-38 for relative cost indices for major cities in the United States in 1975. Determine the cost index for the city closest to the highway project. Determine from the Bureau of Labor Statistics the local cost index for the current year and the local cost index for 1975. The total cost of the barrier can be estimated as follows:

$$\text{Total Cost} = \text{Total Cost Factor} \times \text{Barrier Length} \times \frac{\text{City Cost Index}}{100} \times \frac{\text{Current Cost Index}}{\text{1975 Cost Index}} \qquad (4\text{-}6)$$

Compute and enter the total cost of each barrier option.

Example. The various design options on Figure 4-33 are translated into costs in Figure 4-39, a sample Cost Factor Worksheet. The total cost factors are converted to total costs assuming that the site is located near a city with a relative city cost index determined from Figure 4-38 of 95. It is also assumed that this city had a cost index in 1975 of 106, and at the time of construction has a cost index of 121.9 (equivalent to a 15% inflation). For the design C-2,2,8 above, the total cost is (rounded to the nearest hundred dollars):

$$94.72 \times 8000 \times \frac{95}{100} \times \frac{121.9}{106} = \$827{,}900$$

6.6 These total costs can be used to compare all of the designs with one another. (The cost factor concept can also be used for one specific design to evaluate the cost/benefit of modifications to that design, such as increasing the height by a few feet, increasing or decreasing the length, etc.)

FIGURE 4-38

MAJOR CITIES COST INDEX RELATIONSHIPS

	INDEX NO.		INDEX NO.		INDEX NO.
Anchorage, Alaska	137	Jackson, Miss.	85		
Alburquerque, N.M.	84	Jacksonville, Fla.	88	Raleigh, N.C.	84
Atlanta, Ga.	89	Kansas City, Mo.	96	Reading, Pa.	94
Baltimore, Md.	94	Knoxville, Tenn.	90	Richmond, Va.	86
Birmingham, Ala.	88	Lansing, Mich.	93	Rochester, N.Y.	98
Boise City, Ioa.	90	Las Vegas, Nev.	95	Rock Island, Ill.	91
Boston, Mass.	98	Little Rock, Ark.	91	Sacramento, Cal.	97
Buffalo, N.Y.	100	Los Angeles, Calif.	96	St. Louis, Mo.	96
Burlington, Vmt.	89	Louisville, Ky.	94	St. Paul, Minn.	100
Butte, Mont.	87	Lubbock, Tex.	82	Salt Lake City, Utah	94
Charlston, S.C.	82	Madison, Wis.	98	San Antonio, Tex.	85
Charlston, W.Va.	90	Manchester, N.H.	91	San Diego, Calif.	94
Charlotte, N.C.	82	Memphis, Tenn.	91	San Francisco, Cal.	100
Chattanooga, Tenn.	87	Miami, Fla.	94	Santa Fe, N. Mex.	87
Cheyenne, Wyo.	88	Milwaukee, Wis.	102	Savannah, Ga.	86
Chicago, Ill.	96	Minneapolis, Minn.	97	Schenectady, N.Y.	96
Cincinnati, Ohio	98	Mobile, Ala.	90	Scranton, Pa.	94
Cleveland, Ohio	98	Nashville, Tenn.	90	Seattle, Wash.	89
Columbia, S.C.	85	Newark, N.J.	104	Shreaveport, La.	85
Columbus, Ohio	97	New Haven, Conn.	97	Sioux Falls, S. Dak.	94
Dallas, Tex.	80	New Orleans, La.	90	South Bend, Ind.	95
Dayton, Ohio	95	New York, N.Y.	111	Spokane, Wash.	91
Denver, Colo.	98	Norfolk, Va.	86	Springfield, Mass.	95
Des Moines, Iowa	96	Oakland, Calif.	100	Syracuse, N.Y.	96
Detroit, Mich.	95	Oklahoma City, Okla.	86	Tampa, Fla.	90
Duluth, Minn.	99	Omaha, Nebr.	94	Toledo, Ohio	94
El Paso, Tex.	81	Peoria, Ill.	93	Topeka, Kan.	94
Erie, Pa.	95	Philadelphia, Pa.	97	Trenton, N.J.	99
Evansville, Ind.	93	Phoenix, Ariz.	94	Tulsa, Okla.	90
Fargo, N. Dak.	95	Pittsburgh, Pa.	98	Washington, D.C.	95
Fresno, Calif.	92	Portland, Me.	89	Wichita, Kans.	93
Grand Rapids, Mich.	90	Portland, Ore.	92	Wilmington, Del.	97
Hartford, Conn.	97	Providence, R.I.	95	Worcester, Mass.	96
Houston, Tex.	86	Montreal, Can.	78	York, Pa.	92
Indianapolis, Ind.	94	Toronto, Can.	96	Youngstown, Ohio	98

The above city indices are listed for comparative purposes only. Areas radiating out from the major cities to suburban cities usually lower the cost. Areas remote from labor & material supplies will usually raise prices substantially from major city areas for travel & subsistance & shipping charges.

COST FACTOR WORKSHEET

Wind Loading 30 #/ɸ

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS: Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	TOTAL COST
C-2,2,8-S	1	13	7000	73.27	5.72	12.08		91.07	696,500
C-3,3,8-S	1	13	7000	73.27	4.08	12.08		89.43	683,900
C-2,2,8	2	18	6000	104.67	7.92			112.59	738,000
C-3,3,8	2	18	6000	104.67	10.77			115.44	756,700
C-2,2,8	3	15	8000	88.15	6.57			94.72	827,900
C-3,3,8	3	15	8000	88.15	8.98			97.13	848,900
M-3,6-S	1	13	7000	50.43	36.04	12.08		98.55	753,700
M-3,6	2	18	6000	66.79	49.90			116.69	764,900
M-3,6	3	15	8000	60.37	41.58			101.95	891,000
W-2,2,3-S	1	13	7000	54.27	7.48	12.08		73.83	564,600
W-4,4-S	1	13	7000	54.27	5.98	12.08		72.33	553,100
W-2,2,3	2	18	6000	92.81	11.22			104.03	681,900
W-4,4	2	18	6000	92.81	8.28			101.09	626,600
W-2,2,3	3	15	8000	64.69	9.02			73.71	644,200
W-4,4	3	15	8000	64.69	6.90			71.59	625,700
B(2)-1	2	18	6000	35.50	51.87			87.37	572,700
B(4)-1	2	10	6000	20.16	52.33			122.45	802,700
M-3,6		8	6000	27.78	22.18				

FIGURE 4-39 Use of Cost Factor Worksheet.

In addition to its noise reducing properties, there are several other characteristics of the barrier which should be evaluated. In this step these non-acoustical characteristics are rated.

7.1 Refer to Figure 4-40, the Design Evaluation Worksheet. List in the left two columns the design code and location number for each barrier option, as listed in the Design Option Worksheet.

7.2 Along the top of the Worksheet, under the heading "Functional Assessment," several items are listed which refer to the non-acoustical characteristics, or the functional "performance" of the barrier: aesthetics, durability, ease of maintenance, safety, ease of snow removal, and community acceptance. There is also space for inclusion of other characteristics which may be important, based on local conditions.

7.3 For each of these categories, assign a +, 0, or - rating for each design option. Use of a + rating implies better than average performance for a barrier design in a particular category, and similarly a - rating is indicative of less than average performance. Establishment of rating criteria is necessarily site dependent, and must be determined by the designer based on state and local standards, past experience, knowledge of the community and citizen input. The following guidelines may be useful.

<u>7.3.1</u> The evaluation of aesthetics of noise barriers must, by its nature, be qualitative rather than quantitative. In this area, the judgment of the highway designer as to the local conditions and the appropriate visual treatment of the wall with respect to adjoining land use will be a primary consideration.

FIGURE 4-40

DESIGN EVALUATION WORKSHEET

Design	Location	Functional Assessment								Total Cost (Thousands of $)	Design Goal Met?	Comments
		Aesthetics	Durability	Ease of Maintenance	Safety	Snow Removal	Community Accept.					

7.3.2 Physical durability considerations include the durability of the barrier material to the effects of moisture, temperature changes, wind, and the effects of automotive exhausts, dirt, sand, and salts used in snow removal.

7.3.3 Factors to assess the ease of barrier maintenance are threefold. First is the evaluation of the effect of an impact on the barrier wall from a maintenance standpoint which (with the exception of concrete and concrete masonry units) will require replacement of portions of the barrier. This maintenance factor can be considered proportional to initial installation costs. Second are routine maintenance considerations such as repainting of a surface considering the normal lifespan of paint. The third maintenance consideration is the ease of cleaning the material, which is related to the porosity of the surface to be cleaned.

7.3.4 Safety factors are concerned primarily with the relative safety of the walls in an impact situation. For example, a wall with a facing material which can be dislodged and become a missile is considered less safe than a solid concrete wall or an earth berm. (It is assumed that the barrier location has been selected with safety considerations in mind [Step 2.3].)

7.3.5 Snow removal considerations are with regard to sufficient room for snow storage initially, and then easy removal without disruption of traffic flow.

7.3.6 If community input has been incorporated throughout the design process, assessment of barrier acceptability should be fairly straightforward.

Example. Figure 4-41 illustrates the use of the Design Evaluation Worksheet, for the design option examples above.

4-8 Step 8: Select Barrier

8.1 In the column labeled "Total Cost" on the Design Evaluation Worksheet, enter the total estimated cost from the Cost Factor Worksheet for each barrier option.

8.2 In the last column indicate whether the Design Goal Noise Reduction has been achieved by each design option. Enter qualifying comments as appropriate.

8.3 Based upon the acoustical performance, total cost, and functional characteristics of each barrier, select the design option most appropriate to local conditions. (In evaluating the functional characteristics, it should be remembered that for a particular highway site, some of the characteristics may be much more important than others.)

4-9 Step 9: Design Barrier

9.1 After selection of a specific design, it is desirable to "optimize" the barrier height and length by taking into consideration those factors which were neglected in the original assessment, such as terrain features in the vicinity of the site, and variations in the highway configuration and traffic flow. It is recommended that the TSC computer program

DESIGN EVALUATION WORKSHEET

Design	Location	Functional Assessment								Total Cost (Thousands of $)	Design Goal Met?	Comments
		Aesthetics	Durability	Ease of Maintenance	Safety	Snow Removal	Community Accept.					
C-2,2,8-5	1	+	+	+	+		0			697	Y	
C-3,3,8-5	1	+	+	+	+		0			684	Y	
C-2,2,8	2	+	+	+	0		0			738	Y	
C-3,3,8	2	+	+	+	0		0			757	Y	
C-2,2,8	3	+	+	+	0		0			828	Y	
C-3,3,8	3	+	+	+	0		0			849	Y	
M-3,6-5	1	+	+	+	+		+			754	Y	
M-3,6	2	+	+	+	0		+			765	Y	
M-3,6	3	+	+	+	0		+			891	Y	
W-2,2,3-5	1	+	0	0	+		0			565	Y	
W-4,4-5	1	0	−	−	+		0			553	Y	
W-2,2,3	2	+	0	0	0		0			682	Y	
W-4,4	2	0	−	−	0		0			627	Y	
W-2,2,3	3	+	0	0	0		0			644	Y	
W-4,4	3	0	−	−	0		0			626	Y	
B(2)-1	2	+	+	0	+		+			573	Y	
B(4)-1 / M-3,6	2	+	+	0	+		+			803	Y	

FIGURE 4-41 Use of Design Evaluation Worksheet.

be used to guide the refinement of the barrier dimensions. This would involve first computing accurately the attenuation provided by the selected approximate barrier design, and then adjusting the dimensions of various sections of the barrier, based on the resulting noise levels at critical receivers along the route. While this process may take several iterations before a complete barrier design is developed which provides the desired attenuation at all receivers, it is certainly worthwhile to undertake in light of the potential savings of barrier construction costs for an overdesigned barrier, as well as the potential benefits of avoiding an underdesigned barrier.

9.2 While the TSC methodology can make an accurate assessment of barrier <u>attenuation</u> for a specific design, it does not consider the effects of barrier transmission or multiple reflections. If the transmission loss of the selected barrier material is within 10 dB of the computed barrier attenuation, or if double parallel barriers are present, their effects on the total noise reduction of the final barrier design should be assessed as described in Steps 5.4 and 4.3, respectively. (Note that in assessing the effects of multiple reflections, separate values of ΔBAR should be determined for truck and car sources, to provide an accurate estimate of the net noise reduction of the barrier. To use the Parallel Barrier Nomograph for cars, H_S = 0 feet for both the source and ground image source.)

9.3 If the selected design option involves one of the reference drawings, review the particular drawing to ensure that the assumptions used in the design calculations are appropriate for the site under consideration. Adjust the design details on the reference drawings as necessary for specific conditions at the site.

9.4 If the selected design option is based upon a material not included in the reference drawings, the reference drawings may be used to provide guidance in the detailed design of the barrier.

CHAPTER 5
BARRIER DESIGN EXAMPLES

Examples of the design procedure in Chapter 4 are presented in this chapter. The first example involves a rather simple highway/community configuration, for which a single uniform barrier is required. The second example considers the effects of parallel barriers. Finally, the third example deals with a more complicated configuration which requires a segmented barrier design.

For additional examples refer to Appendix D, in which the design procedure has been applied to five actual highway sites where barriers have been constructed.

5-1. Basic Example of Barrier Design

Figure 5-1 shows a typical community adjacent to an at-grade highway. Assume high volume, high speed traffic flow on the highway with a 5% truck mix. Based on noise level projections determined using the 117/144 methodology, critical receivers have been selected in pairs at each end of the community and in the middle of the community. Each pair consists of a receiver close-in to the highway, and a receiver farther out for whom an L_{10} criterion of 70 dBA is exceeded. The six selected receivers are indicated in the Figure, with the projected pre-barrier noise levels and the near and far lane distances shown for each receiver. Note that although Receiver 6 has a projected level of 69.5 dBA, it is included as a critical receiver in anticipation of a possible increase in noise level resulting from potential loss of ground absorption effects when the barrier is installed. (Also note that

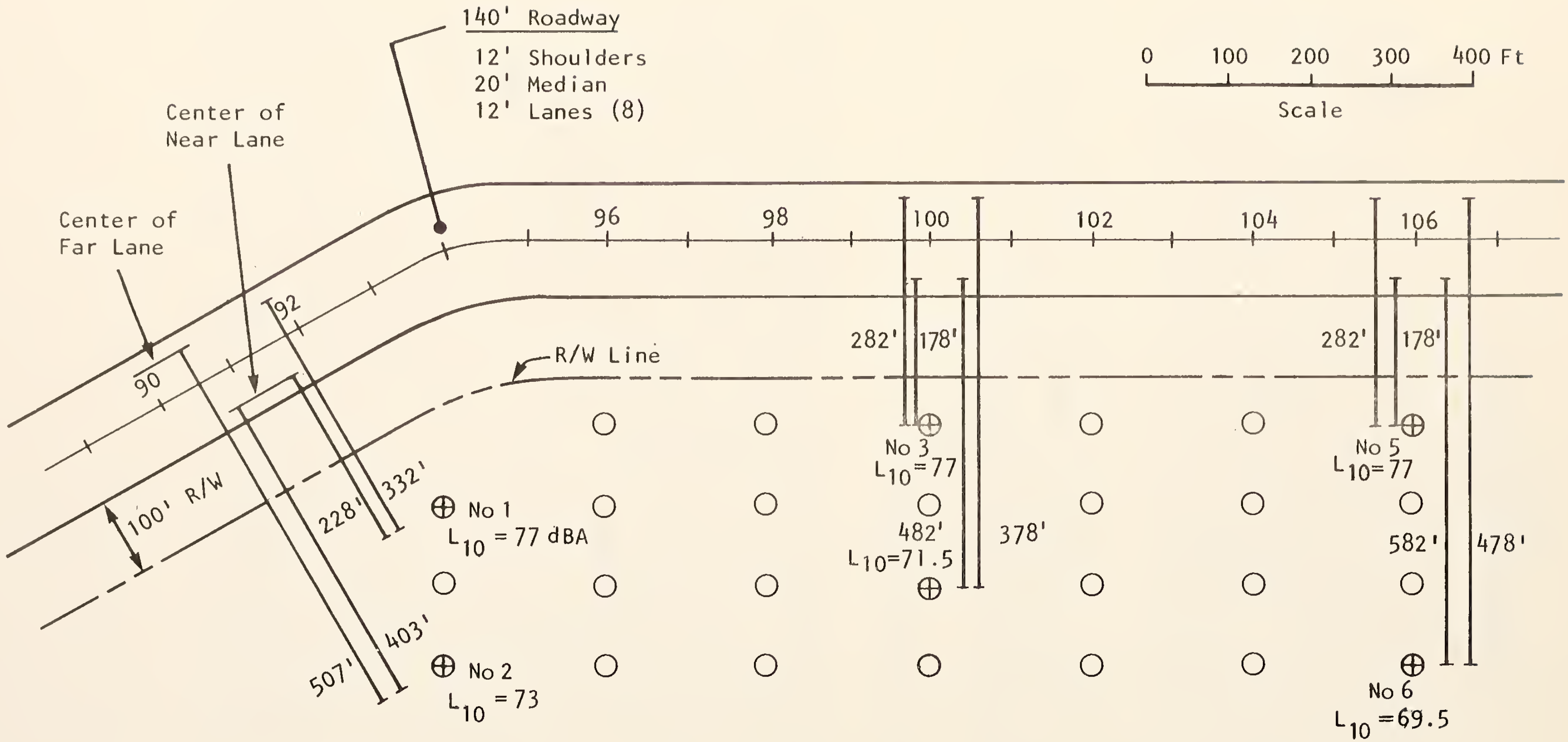


FIGURE 5-1 Sample Highway/Community Scenario.

noise levels are not uniform along the back of the community because of differences in shielding provided by intervening rows of houses: Receiver 2 experiences essentially no benefits from this shielding, Receiver 4 benefits from two complete rows, and Receiver 6 benefits from house shielding for only the left portion of the highway.)

With this information, Figure 5-2 illustrates the use of the Design Goal Worksheet. Note that Figure 4-3 has been used to determine Δ_G, and that in the absence of other shielding elements, Δ_G is added to the Insertion Loss to yield a Design Goal noise reduction.

For this example the community is assumed to be at road level elevation, and the vertical configuration of the highway is assumed to be unchanged along its length adjoining the community. There are no intersecting ramps or streets in the vicinity of the community. A wind loading requirements of 30 pounds/square foot is assumed to be appropriate for the area.

Figure 5-3 shows a cross section through the highway and middle column of receivers (including Receivers 3 and 4) at Station 100. On the figure, car and truck sources are located at the equivalent lane distance from Receiver 3. A trial barrier location is established three feet beyond the highway shoulder; L/S and P are indicated on the figure. For a Design Goal noise reduction of 10.5 dB, a trial truck attenuation of 8.5 is chosen, and $\Delta H = (8.5 - 5) \times 2 = 7$ feet. Thus, H = 14 feet and B = 7 feet. Using these parameters, the Barrier Nomograph is used to determine that a subtended angle of 163° is required (see Figure 5-4).

DESIGN GOAL WORKSHEET

Step	Item	Receiver 1	Receiver 2	Receiver 3	Recevier 4	Receiver 5	Receiver 6
1	D_E, ft	275	452	224	427	224	527
2	L_B, dBA	77	73	77	71.5	77	69.5
3	L_C, dBA	70	70	70	70	70	70
4	$L_B - L_C$, dBA	7	3	7	1.5	7	-0.5
5	Method	117/144	117/144	117/144	117/144	117/144	117/144
6	Δ_S, dBA	—	—	—	—	—	—
7	Δ_G, dBA	3.5	5	3.5	4.5	3.5	5
8	NR, dBA	10.5	8	10.5	6	10.5	4.5
9	NR $\geq$ 20?	NO	NO	NO	NO	NO	NO

FIGURE 5-2 Use of Design Goal Worksheet.

Note: Distorted Scale

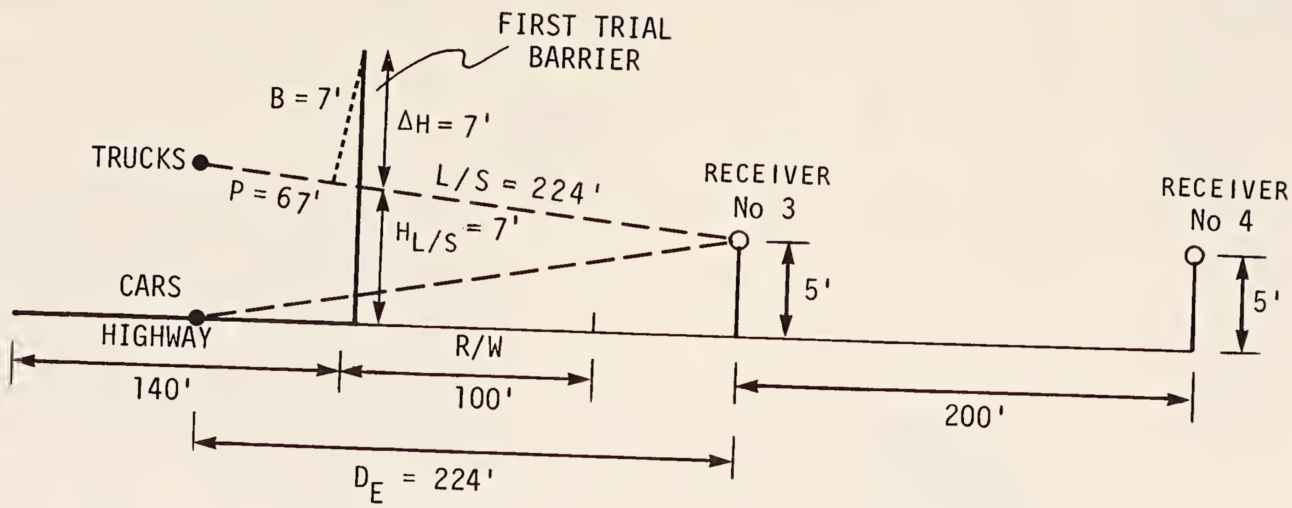


FIGURE 5-3 Cross Section Through Receivers 3 and 4 (Station 100).

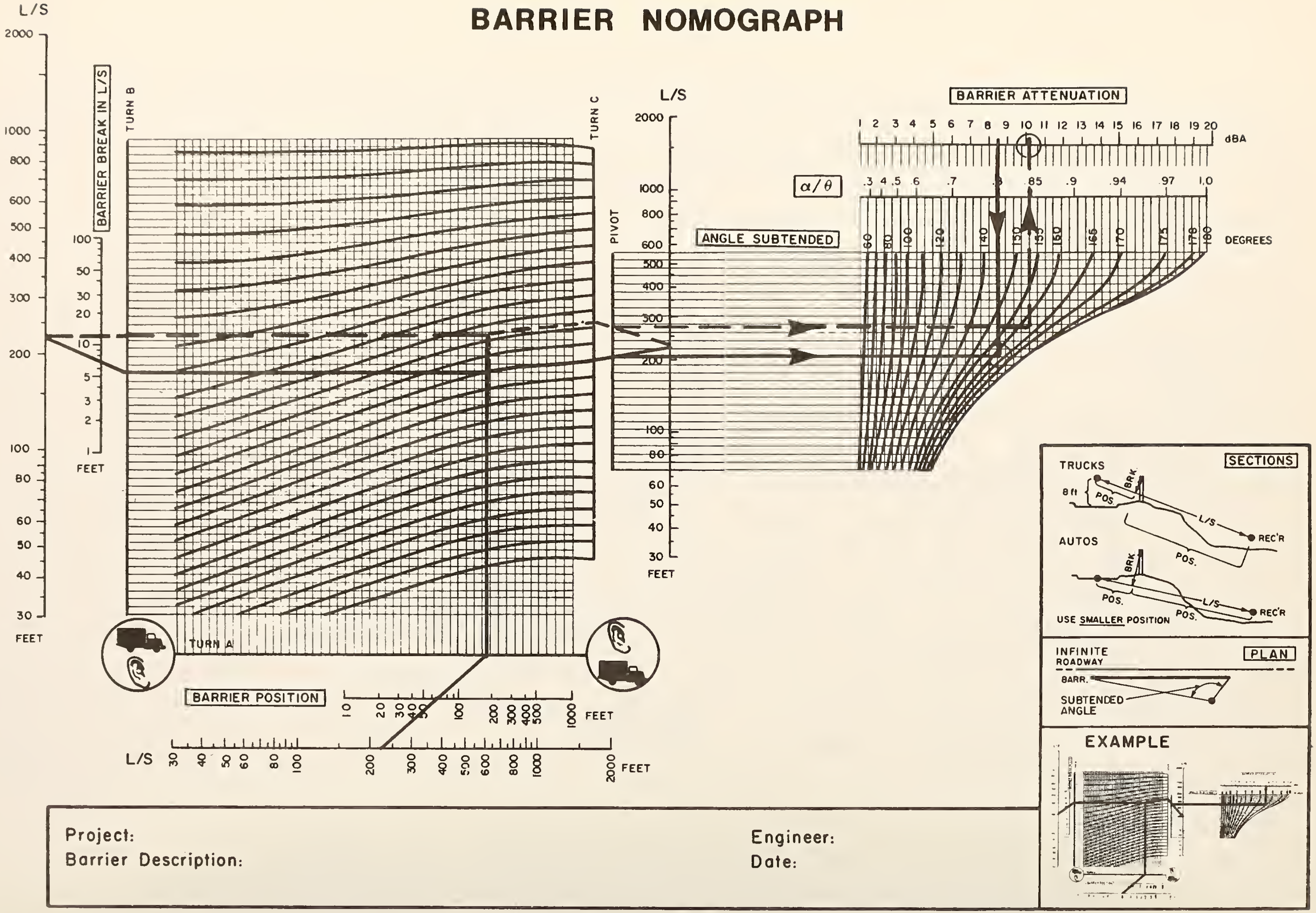


FIGURE 5-4 Use of Nomograph for Trial 14 Foot Barrier.

For this barrier, B = 12 feet for car sources. Applying the Barrier Nomograph shows that the car attenuation is 10 dB (see Figure 5-4). Referring to Figure 4-17, it can be seen that for a 5% truck mix at 55 mph, with a 1.5 dB difference in car and truck attenuations (10 - 8.5 = 1.5), the total attenuation is only 0.5 dB above that for trucks in this case. Thus the total attenuation is 9 dB, which is 1.5 dB too low.

On this basis a new trial height is evaluated based on a trial truck attenuation of 8.5 + 1.5 = 10 dB. This new height of 17 feet results in a B of 10 feet for trucks and 15 feet for cars. Using the Barrier Nomograph a subtended angle of 165° is necessary to give a truck attenuation of 10 dB (see Figure 5-5); this results in a car attenuation of 11 dB. According to Figure 4-17 the total attenuation is then 10.5 dB, which meets the Design Goal.

Several walls of varying heights and lengths can be constructed to provide the 10 dB truck attenuation. Working backwards through the nomograph, the heights and lengths of four possible walls are determined, as listed on Figure 5-6. Note from this figure that the lowest wall is extremely long. By increasing the wall height 3 feet (from 14 to 17 feet), the necessary length is reduced a factor of three. However, to reduce wall length even further requires a much greater increase in wall height. Another important factor is consideration of other receivers; since the community extends 600 feet on either side of Receiver 3, it would not be desirable to consider walls much shorter than the 2400 foot wall (1200 feet on each side of

BARRIER NOMOGRAPH

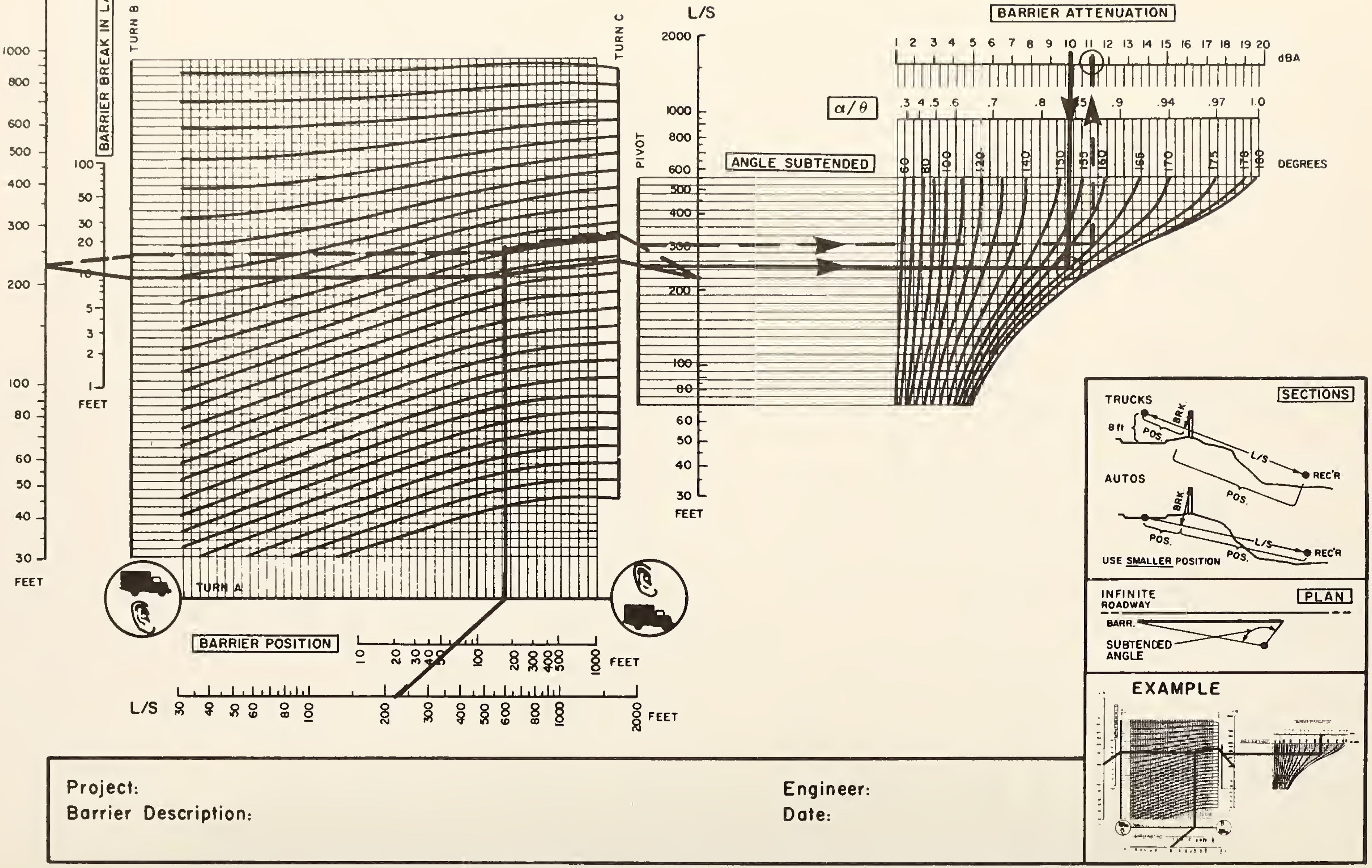


FIGURE 5-5 Use of Nomograph for Trial 17 Foot Barrier.

FIGURE 5-6

POSSIBLE BARRIER DIMENSIONS

Subtended Angle	Length, ft.	Height, ft.	Length x Height, sq. ft.
175°	7200	14	100,800
170°	3600	16	57,600
165°	2400	17	40,800
160°	1800	24	43,200

the receiver, from Station 88 to Station 112). Thus, based on all considerations the 17 foot high, 2400 foot long wall at this location seems to be the best choice at this point in the analysis.

Using the Barrier Nomograph, the attenuation at Receiver 4 is seen to be 7.5 dB for this wall, which exceeds the required 6 dB.

Since the roadway curves, the barrier will wrap around Receivers 3 and 4, and thus the wall need not extend a full 1200 feet to the left to provide the required attenuation for these receivers. However, the attenuation requirements for Receivers 1 and 2 cannot be satisfied unless the wall is indeed extended further to the left. Using the Barrier Nomograph it can readily be determined that the 17 foot barrier should begin approximately at Station 83.

For Receivers 5 and 6, the wall extends just far enough (to Station 112) to provide the Design Goal attenuations. If additional receivers were located to their right, the wall would have to be extended as necessary, or projected away from the highway towards the community, to provide the required subtended angle.

To summarize, a wall of 17 foot height, located 3 feet from the shoulder (15 feet from the edge of the near lane), and extending for 2900 feet along the roadway (1700 feet to the left of Receiver 3 and 1200 feet to the right from Stations 83 to 112, provides the Design Goal attenuation for all critical receivers. In a similar manner, walls of different heights and lengths can be designed for other locations; since a wide right-of-way is available, locations in the middle of the right-of-way and near the right-of-way line could be evaluated.

Based on discussions with community groups, the barrier materials under consideration should include both masonry blocks and wood. For comparison purposes a basic concrete wall is also under consideration. Climatic conditions dictate the need for weathering treatments in the barrier design. Also, the proximity of the barrier to the highway indicates the need for a safety barrier.

Figure 5-7 shows a Design Option Worksheet incorporating these various considerations for the 17-foot barrier described above. The Cost Factor Worksheet for these options is presented in Figure 5-8; total costs are based on a city index of 95, and 1975 and current cost indices of 111 and 120, respectively. Finally, Figure 5-9 is a sample Design Evaluation Worksheet. From the information displayed on this worksheet (when all locations and options are included), a single design can be selected which best satisfies acoustic and functional requirements and cost constraints.

5-2. Parallel Barrier Example

For the same highway/community configration examined in Section 5-1, assume that another 17-foot barrier is to be built on the opposite side of the roadway to protect a community in that area. This barrier will also be located 3 feet from the shoulder (15 feet from the near lane), but will begin at Station 96 and proceed to the right for 2000 feet.

DESIGN OPTION WORKSHEET

LOCATION NUMBER
Position / Height / Length

MATERIAL	No. 1 15 / 17 / 2900	No. 2 / /	No. 3 / /
MASONRY	M-1,6-S		
	M-2,6-S		
	M-3,6-S		
WOOD	W-3-S		
	W-2,3-S		
	W-1,5,5-S		
CONCRETE	C-8-S		

Wind Loading	30 #/□	Safety Barrier	FOR LOCATION No. 1
Aesthetics	YES	Absorption	NO
Weathering	YES	Other Comments	

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
M-1,6	MASONRY W/SCORED BLOCK, INTEGRAL COLOR	NO
M-2,6	W/6" SLUMP BLOCK, INTEGRAL COLOR	NO
M-3,6	W/4" SLUMP BLOCK, INTEGRAL COLOR	NO
W-3	WOOD W/PRESERVATIVE	NO
W-2,3	W/WOOD BATTENS, PRESERVATIVE	NO
W-1,5,5	W/PLYWOOD FACING, STAIN BOTH SIDES	NO
C-8	CONCRETE W/INTEGRAL COLOR	NO

FIGURE 5-7 Design Option Worksheet for Basic Example.

COST FACTOR WORKSHEET

Wind Loading 30#/ф

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS					TOTAL COST
				Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	
M-1,6-S	1	17	2900	64.65	16.45	12.08	-	93.18	277,500
M-2,6-S	1	17	2900	64.65	52.00	12.08	-	128.73	383,400
M-3,6-S	1	17	2900	64.65	47.11	12.08	-	123.84	368,800
W-3-S	1	17	2900	83.43	4.74	12.08	-	100.25	298,600
W-2,3-S	1	17	2900	83.43	7.67	12.08	-	103.18	307,300
W-1,5,5-S	1	17	2900	83.43	15.84	12.08	-	111.35	331,600
C-8-S	1	17	2900	99.17	.39	12.08	-	111.64	332,500

FIGURE 5-8 Cost Factor Worksheet for Basic Example.

DESIGN EVALUATION WORKSHEET

Design	Location	Functional Assessment: Aesthetics	Durability	Ease of Maintenance	Safety	Snow Removal	Community Accept.			Total Cost (Thousands of $)	Design Goal Met?	Comments
M-1,6-S	1	+	+	+	+		0			278	Y	
M-2,6-S	1	+	+	+	+		0			383	Y	
M-3,6-S	1	+	+	+	+		+			369	Y	
W-3-S	1	0	0	+	+		0			299	Y	
W-2,3-S	1	+	0	+	+		+			307	Y	
W-1,5,5-S	1	+	0	+	+		0			332	Y	
C-8-S	1	-	+	+	+		-			333	Y	

FIGURE 5-9 Design Evaluation Worksheet for Basic Example.

The impact of this second barrier on the design of the first barrier is determined using the Parallel Barrier Nomograph. The barrier separation W is 146 feet, the receiver to barrier distance D_B for the closest receiver (No. 3) is 157 feet, and the barrier height H is 17 feet. The receiver is clearly in Region I with a height H_R of 5 feet. From the preceding example, the barrier attenuation at this receiver for truck sources is 10 dB. Using the Barrier Nomograph the attenuation for truck sources for a receiver at ground level (H_R = 0) is found to be 10.5 dB.

Figure 5-10 illustrates the use of the Parallel Barrier Nomograph with these values (solid line) to determine that the degradation in barrier performance due to the second barrier is 4.5 dB. The resulting barrier noise reduction is thereby reduced to 5.5 dB, well below design requirements.

The dashed line on Figure 5-10 show that use of an absorptive treatment on the barrier with a noise reduction coefficient of 0.6 will reduce ΔBAR to 1 dB; an absorptive treatment with NRC = 0.8 will reduce ΔBAR to within one-half dB, essentially eliminating the multiple reflection effects.

Figures 5-11 and 5-12 show design options and costs, respectively, of various alternative barrier designs which incorporate absorptive treatments.

5-3. Example of Variation in Highway Configuration

Refer again to Figure 5-1. For this example the highway is depressed by five feet up to Station 96, then transitions at 2% to an at-grade facility from Station 98 + 50 on. The

PARALLEL BARRIER NOMOGRAPH

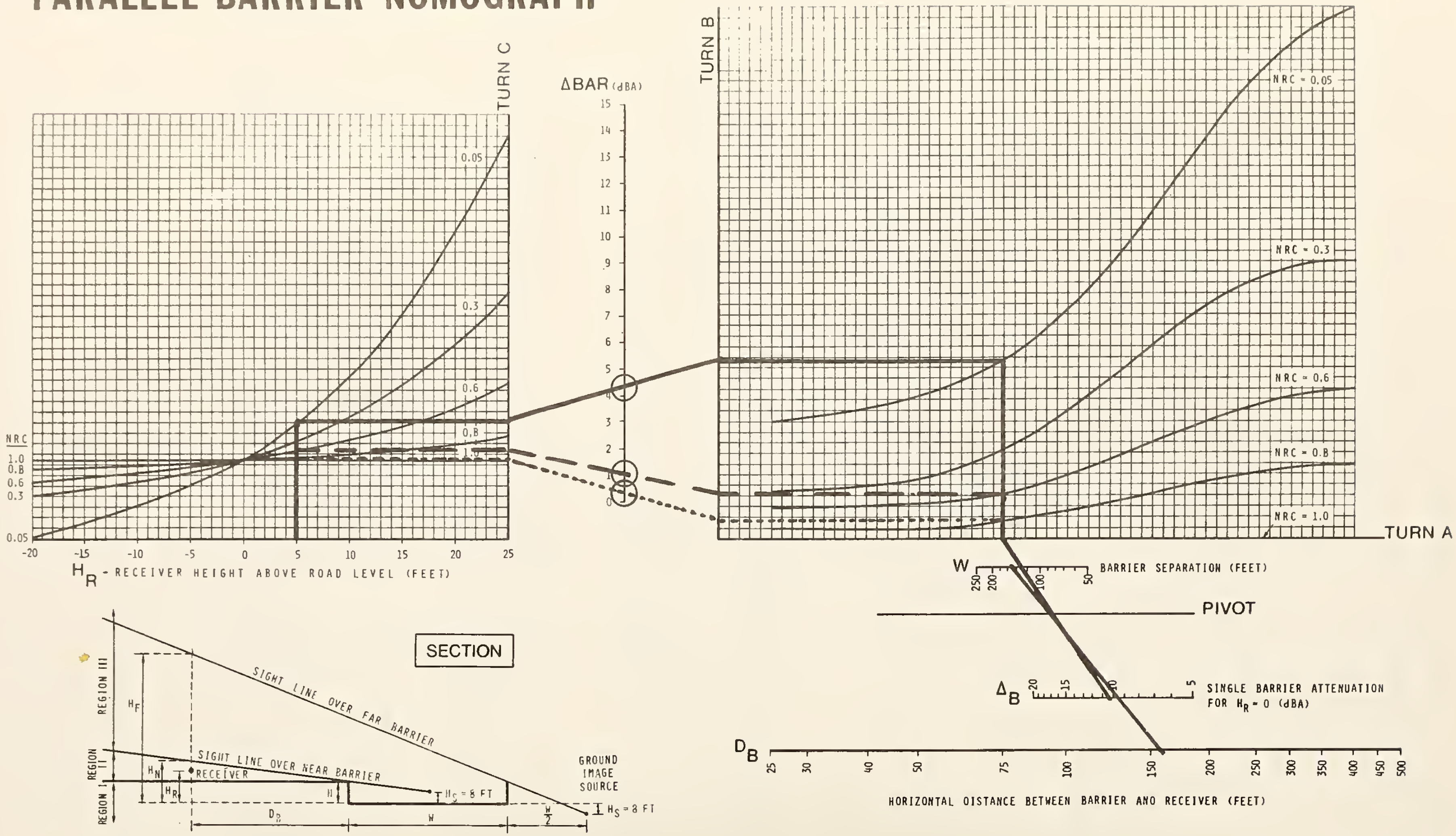


FIGURE 5-10 Parallel Barrier Example.

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 15 / 17 / 2900	No. 2 / /	No. 3 / /
MASONRY	M-S-a1(1)		
	M-1,6-S-a4		
WOOD	W-3-S-a4		
	W-1,5-S-a4		
CONCRETE	C-8-S-a3		
	C-8-S-a4		

Wind Loading	30#/ft	Safety Barrier	FOR LOCATION NO. 1
Aesthetics	YES	Absorption	YES
Weathering	YES	Other Comments	

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED?
M-a1(1)	SOUNDBLOX W/PAINT	YES BY 1dB
M-1,6-a4	SCORED BLOCK/INTEGRAL COLOR W/GLASS	
	FIBER BATTS AND WOOD SCREEN	NO
W-3-a4	WOOD/PRESERV. W/GLASS FIBER + WOOD SCREEN	NO
W-1,5-a4	WOOD/PLYWOOD FACING/STAIN W/GLASS	
	FIBER + WOOD SCREEN	NO
C-8-a3	CONCRETE/INTEGRAL COLOR/VERMICULITE	YES BY 1dB
C-8-a4	CONCRETE/INTEGRAL COLOR/GLASS	
	FIBER + WOOD SCREEN	NO

FIGURE 5-11 Design Option Worksheet for Absorptive Barrier Designs.

COST FACTOR WORKSHEET

Wind Loading 30#/□

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS: Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	TOTAL COST
M-S-a1(1)	1	17	2900	64.65	4.30	12.08	18.96	99.99	297,800
M-66-S-a4	1	17	2900	64.65	16.45	12.08	24.66	117.84	351,000
W-3-S-a4	1	17	2900	83.43	4.74	12.08	24.66	124.91	372,000
W-1.5-S-a4	1	17	2900	83.43	12.91	12.08	24.66	133.08	396,400
C-8-S-a3	1	17	2900	99.17	.39	12.08	43.62	155.26	462,400
C-8-S-a4	1	17	2900	99.17	.39	12.08	24.66	136.30	406,000

FIGURE 5-12 Cost Factor Worksheet for Absorptive Barrier Designs.

sides of the cut have a 2:1 slope, so that the top of the cut is 10 feet from the edge of the shoulder.

In order to provide the required attenuation for Receivers 1 and 2 as indicated in Figure 5-2, a barrier placed along the top of the cut slope which transitions into the 17 foot barrier located 3 feet from the shoulder can be used. For the same length barrier as in the at-grade example (i.e., beginning at Station 83), the height of the barrier along the depressed section need only be 13 feet. Figure 5-13 shows profiles of the roadway and barriers, for both the original at-grade facility and the current example with a depressed section. Note that the 17 foot barrier should begin no later than Station 96, to avoid creating a poorly shielded section as the traffic emerges from the depression.

Figure 5-14 illustrates different approaches which can be taken to connect the walls. Note that if the walls are not connected, there should be an overlap provided, and absorptive treatment applied along the overlap section.

Estimated costs for this segmented wall are easily determined by defining the cost factors and then total costs for each section, and then adding.

One final word of caution is in order: once a barrier design option has been selected, any design such as this which is complicated by variations in highway configuration, terrain irregularities, the presence of ramps, etc, should be evaluated by computer to ensure that weak spots have not been overlooked.

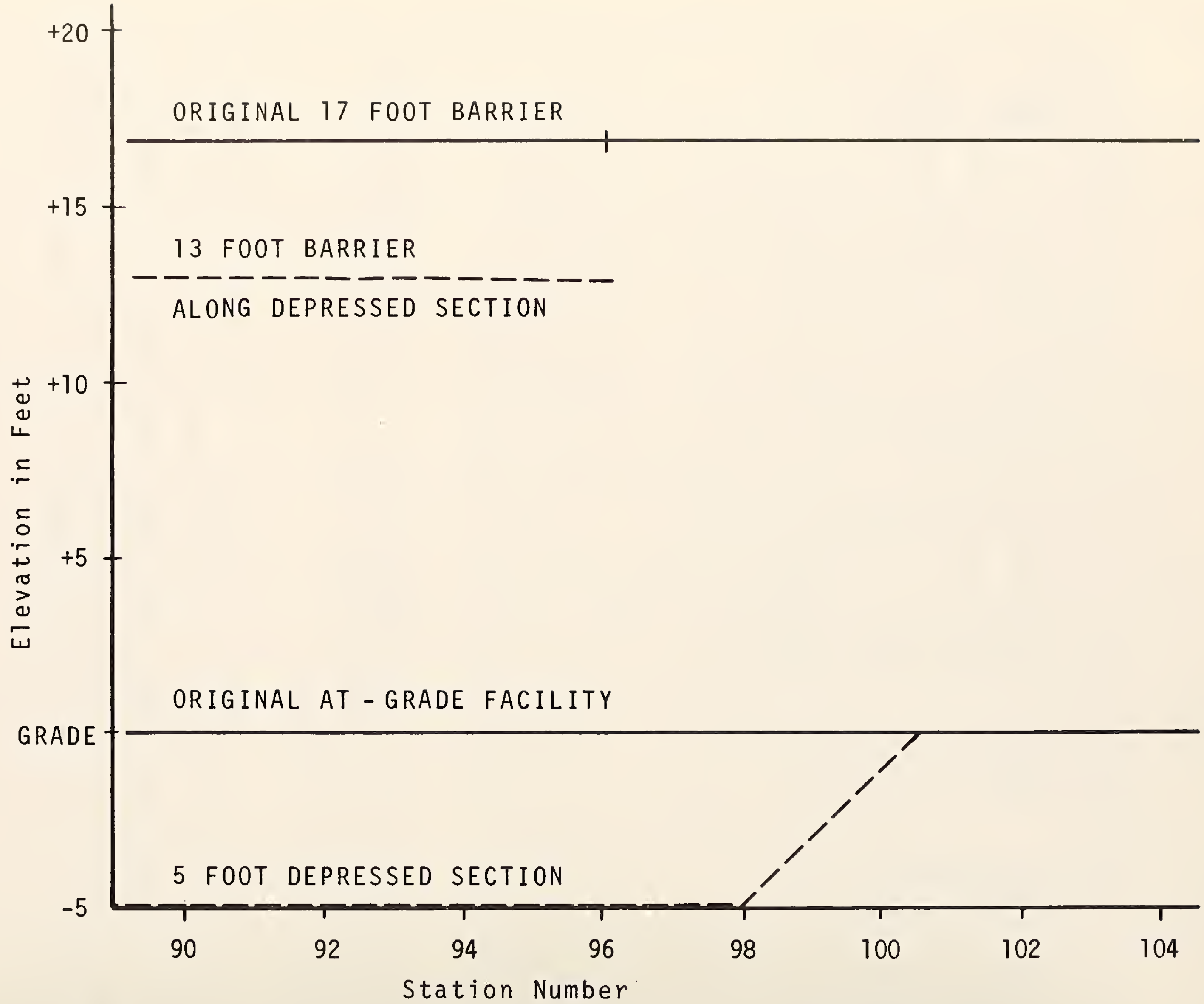


FIGURE 13 Roadway and Barrier Profiles.

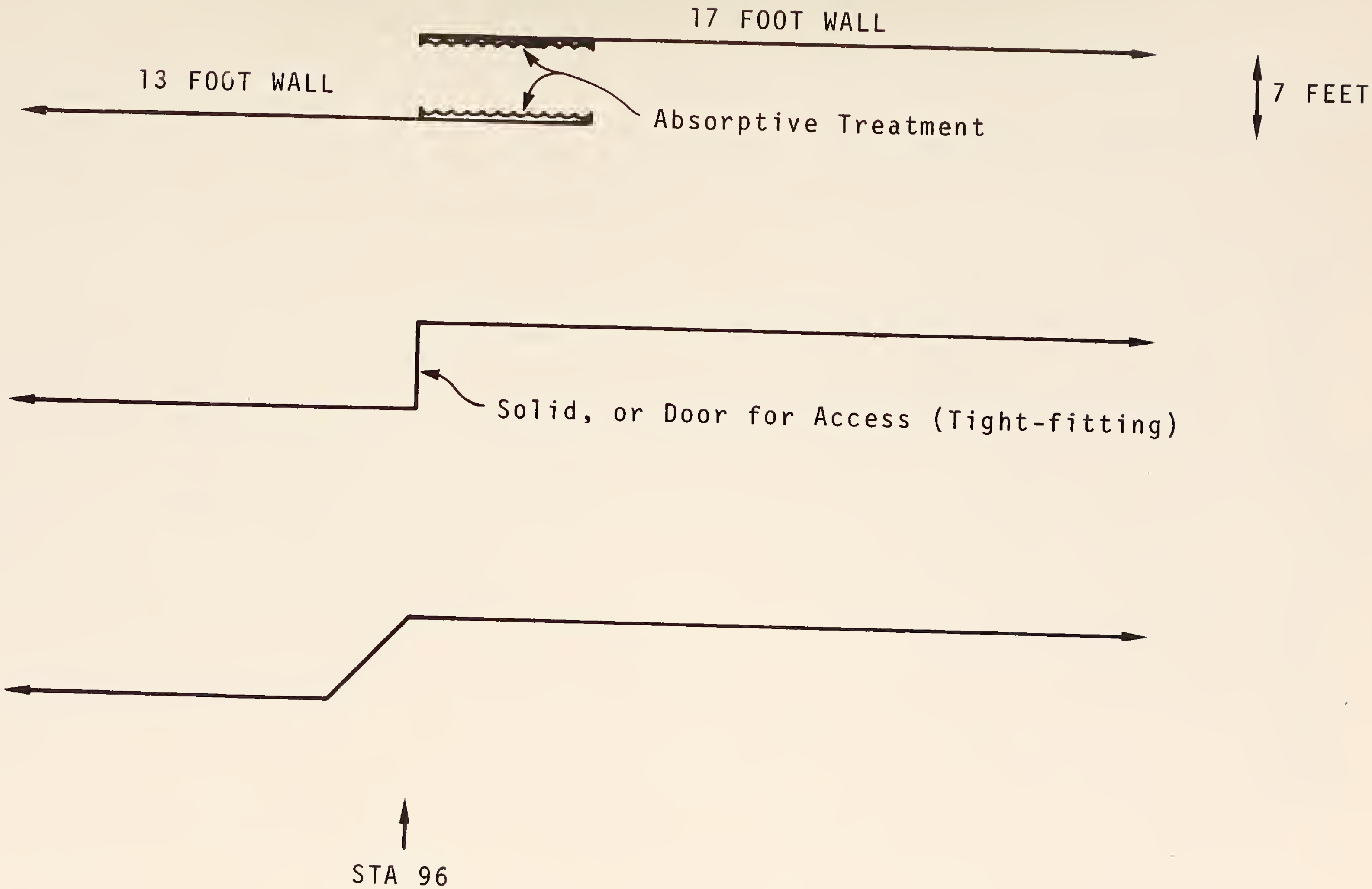
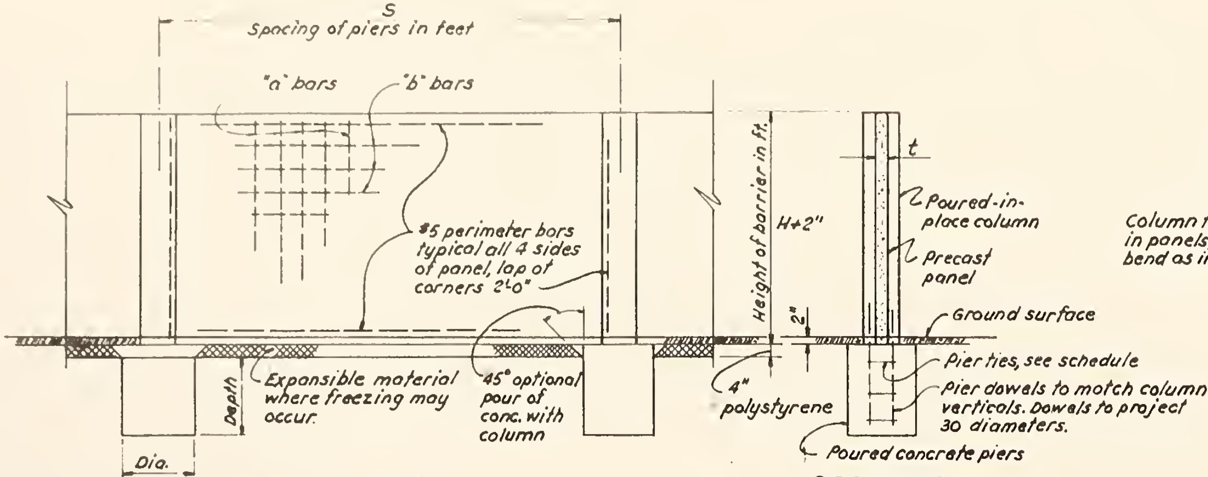


FIGURE 5-14 Alternate Approaches to Connecting 13 and 17 Foot Barrier Walls.

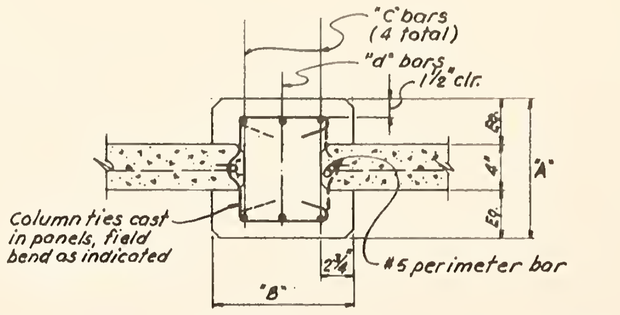
APPENDIX A

REFERENCE DRAWINGS FOR WALLS AND BERMS

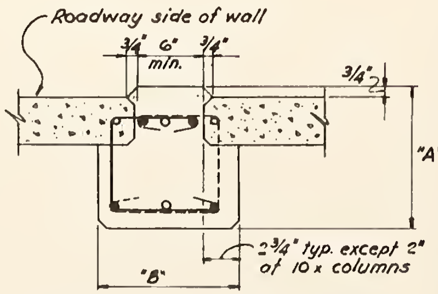


ELEVATION

SECTION



COLUMN CENTERED ON WALL



COLUMN RECESSED FOR "FLUSH" TRAFFIC FACE

SCHEDULE

		Panel				Column				Pier			
20#/ϕ wind load													cost factor
H	S	t	a bars	b bars	Mesh	A x B	c bars	d bars	Col. Ties	Dia.	Depth	Pier Ties	
5	12'-0"	4"	#3 @ 12"	#3 @ 10"	6x10/D5.D5	10"x10"	4-#5	—	#2 @ 10"	16"	5'-0"	#3 @ 10"	23.69
10	12'-0"	4"	#3 @ 12"	#3 @ 10"	6x10/D5.D5	10"x10"	4-#6	—	#2 @ 10"	24"	7'-0"	#3 @ 12"	49.91
15	12'-0"	4"	#3 @ 12"	#3 @ 10"	6x10/D5.D5	12"x12"	4-#7	—	#2 @ 10"	30"	9'-0"	#3 @ 12"	86.60
20	12'-0"	4"	#3 @ 12"	#3 @ 10"	6x10/D5.D5	12"x12"	4-#7	—	#2 @ 12"	30"	10'-0"	#3 @ 12"	127.65
30#/ϕ wind load													
H	S	t	a bars	b bars	M	A x B	c bars	d bars	Col. Ties	Dia.	Depth	Pier Ties	
5	12'-0"	4"	#3 @ 12"	#3 @ 8"	6x10/D7.D5	10"x10"	4-#5	—	#2 @ 10"	16"	6'-0"	#3 @ 10"	26.57
10	12'-0"	4"	#3 @ 12"	#3 @ 8"	6x10/D7.D5	12"x12"	4-#6	—	#2 @ 12"	24"	8'-0"	#3 @ 12"	50.95
15	12'-0"	4"	#3 @ 12"	#3 @ 8"	6x10/D7.D5	15"x12"	4-#7	2-#6	#3 @ 12"	30"	10'-0"	#3 @ 12"	88.15
20	12'-0"	4"	#3 @ 12"	#3 @ 8"	6x10/D7.D5	15"x12"	4-#7	2-#6	#3 @ 12"	30"	12'-0"	#3 @ 12"	115.69
40#/ϕ wind load													
H													
5	12'-0"	4"	#3 @ 12"	#3 @ 6"	4x10/D6.D5	10"x10"	4-#6	—	#2 @ 10"	16"	7'-0"	#3 @ 10"	26.16
10	12'-0"	4"	#3 @ 12"	#3 @ 6"	4x10/D6.D5	12"x12"	4-#6	—	#2 @ 12"	24"	9'-0"	#3 @ 12"	51.87
15	12'-0"	4"	#3 @ 12"	#3 @ 6"	4x10/D6.D5	15"x12"	4-#7	2-#7	#3 @ 12"	30"	11'-0"	#3 @ 12"	85.91
20	12'-0"	4"	#3 @ 12"	#3 @ 6"	4x10/D6.D5	15"x12"	4-#7	2-#7	#3 @ 12"	30"	13'-0"	#3 @ 12"	117.30

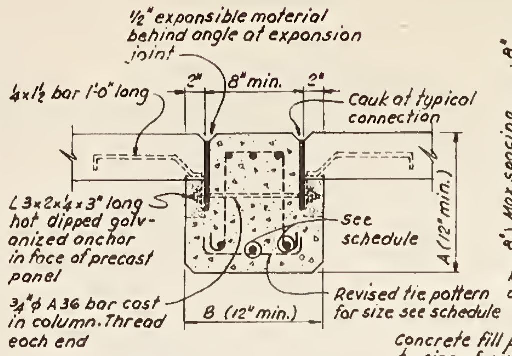
Notes: See C-2 for General Notes and details.

The deformed mesh indicated above in the schedule is an alternate form of panel reinforcement to the reinforcing bars indicated as 'a' and 'b'.

C

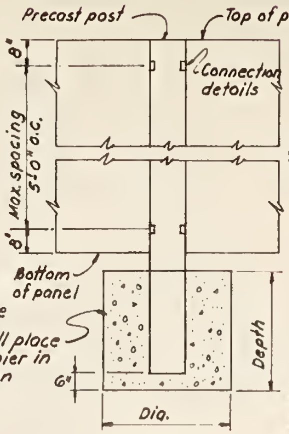
ACOUSTIC BARRIER
CONCRETE

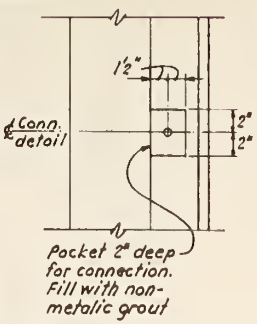
C-1



PRECAST COLUMN WITH FLUSH FACE

Column to be set in pier hole 6" above bottom





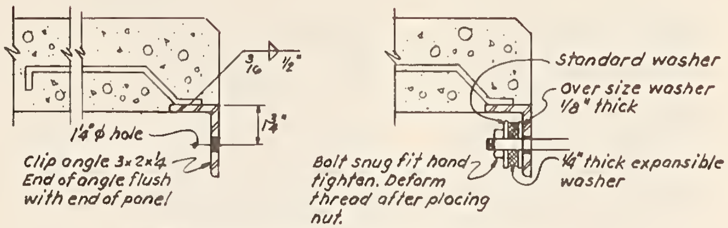
CONN. DETAIL ON PRECAST COLUMN

GENERAL NOTES:

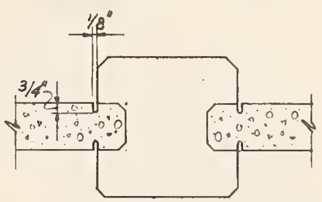
1. GENERAL
   a. Height of barrier shall be based on acoustic requirements.
   b. Barrier walls having a height (H) not indicated in the tables shall be constructed as shown in the next higher height category.
   c. Cast factor column indicates relative cost per lineal foot of acoustic barrier.
2. CONCRETE PANELS
   a. Concrete panels shall be precast from concrete developing 3000 lbs. per sq. in. compressive strength at 28 days.
   b. Reinforcing steel in panels shall conform to ASTM A 615 grade 40 and mesh if used shall conform to ASTM A 497.
   c. The reinforcing shall be placed in the middle of the panel, or where surface treatment reduces the cross section of the panel, it shall be placed at the middle of the net section of such panels.
   d. The perimeter bar indicated shall be continuous around the panel, lapped as noted.
   e. The expansible material under the panel and the contour of the bottom of the panel shall be adapted to local climatic and topographic restraints.
3. CONCRETE POSTS
   a. Concrete for posts either precast or cast in place shall develop 3000 lbs. per sq. in. compressive strength of 28 days.
   b. Post reinforcing shall conform to ASTM A 615 grade 40.
   c. Precast post shall project down to 6" above bottom of pier.
4. CONCRETE PIERS
   a. Concrete in piers shall have a 28 day compressive strength of 2500 lbs. per sq. in.
   b. Concrete shall be placed in drilled piers utilizing the earth as a form.
5. FOUNDATIONS
   a. The drilled piers have been designed utilizing an allowable passive pressure of 300 lbs. per sq. ft. and using the following formula: $D = \left(\frac{14.52\,M}{pd}\right)^{1/3}$

      M = Moment at top of drilled pier (ft. lbs.)
      p = Allowable passive pressure (300 lbs/sq. ft.)
      d = Diameter of pier (ft.)
      D = Depth of pier (ft.)

Note that depth D shall be measured from the top of soil level capable of providing lateral support.

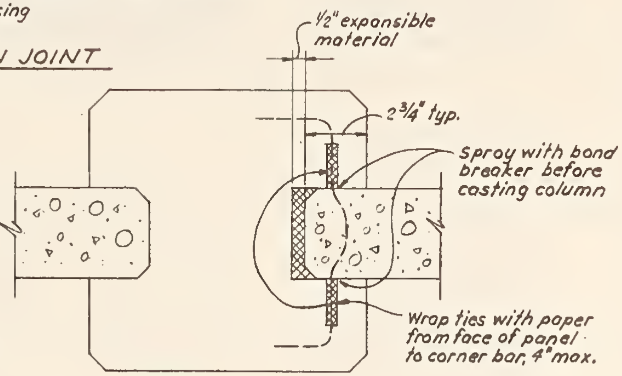


DETAILS AT CONTRACTION JOINT



CONTRACTION JOINT DETAIL

Weakened plane full height of panel.
Space as required by local restraints.



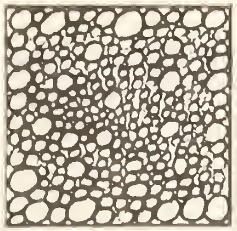
EXPANSION JOINT DETAIL

Space as required by local restraints.

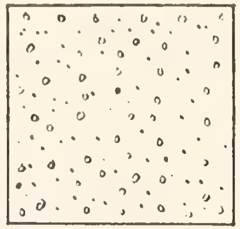
POURED IN PLACE COLUMNS

ACOUSTIC BARRIER
CONCRETE

C-2

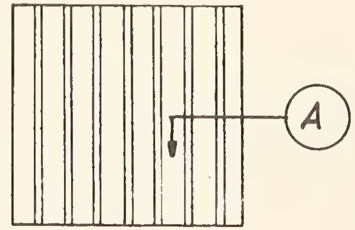


(1) EXPOSED AGGREGATE

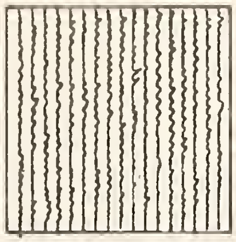


(2) SANDBLAST

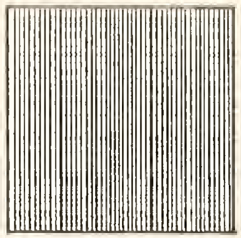
(3) ROUGHSAWN RANDOM WIDTH BOARD FORM



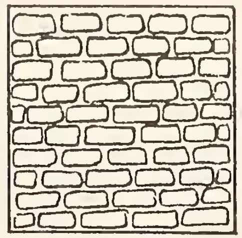
(4) WOOD FORM INSERTS



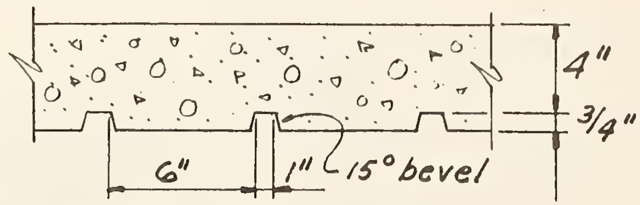
(5) REINFORCING BAR INSERTS



(6) RUBBER MAT INSERTS



(7) IMPRINT "BOMANITE"



SECTION (A)

SCHEDULE

H	(1)	(2)	(3)	(4)	(5)	(6)	(7)	Integral color	Paint
5'	1.32	1.04	3.34	3.74	3.57	4.25	2.01	.12	1.15
10'	2.65	2.07	6.67	7.48	7.13	8.51	4.03	.23	2.30
15'	3.97	3.11	10.01	11.21	10.70	12.76	6.04	.35	3.45
20'	5.29	4.14	13.34	14.95	14.26	17.02	8.05	.46	4.06

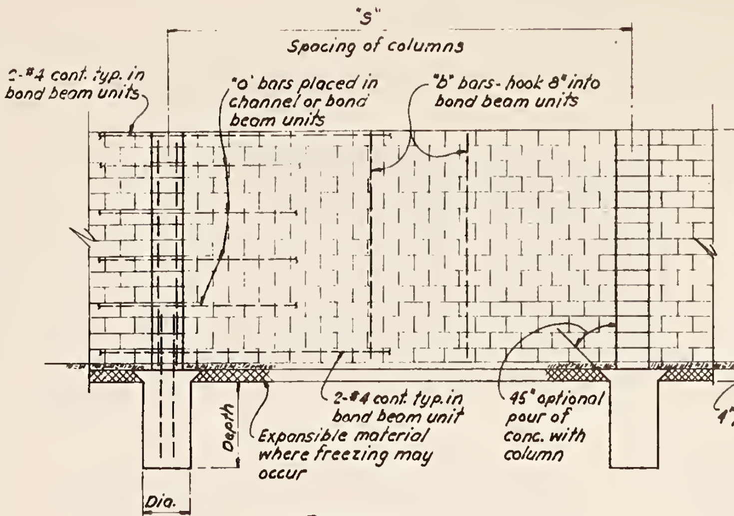
C-1 2 3 4 5 6 7 8 9

Notes:

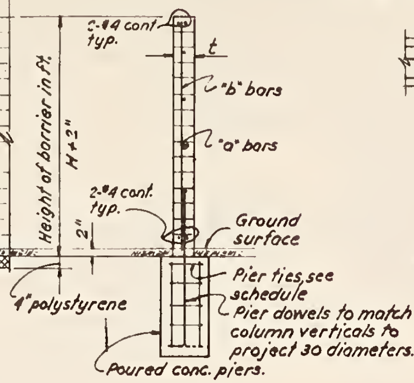
1. All notes on sheet C-1 apply to this drwg.
2. Cost factor for alternate concrete surface treatment additional cost per lineal foot of wall for one side only.

C-3

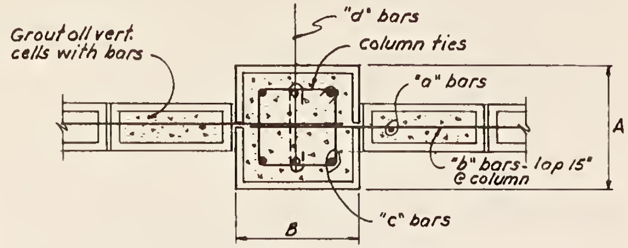
ACOUSTIC BARRIER
ALTERNATE CONCRETE
SURFACE TREATMENT



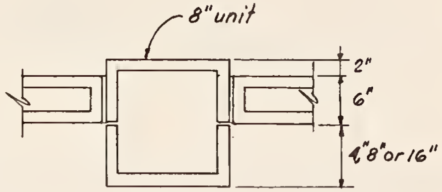
ELEVATION



SECTION



TYPICAL COLUMN PLAN DETAIL



OPTIONAL COLUMN PLAN DETAIL

SCHEDULE

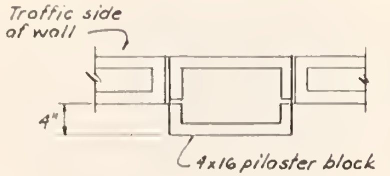
Wall					Column				Piers			
20#/ϕ wind load												
H	S	t	"a" bars	"b" bars	A x B	"c" bars	"d" bars	Ties	Dia.	Depth	Pier Ties	Cost Factor
5'	12'-0"	6"	#4@24"o.c.	#4@48"o.c.	10"x16"	2-#5 EF	—	#2@10"o.c.	16"	5'-0"	#3@10"o.c.	15.75
10'	12'-0"	6"	#4@24"o.c.	#4@48"o.c.	16"x16"	2-#6 EF	—	#2@12"o.c.	24"	7'-0"	#3@12"o.c.	34.50
16'	12'-0"	6"	#4@24"o.c.	#4@48"o.c.	22"x16"	2-#7 EF	—	#2@12"o.c.	30"	9'-0"	#3@12"o.c.	55.89
20'	10'-8"	6"	#4@24"o.c.	#4@48"o.c.	22"x16"	2-#7 EF	1-#6 EF	2-#2@12"o.c.	30"	10'-0"	#3@12"o.c.	69.00
30#/ϕ wind load												
5'	12'-0"	6"	#4@24"o.c.	#4@48"o.c.	10"x16"	2-#5 EF	—	#2@10"o.c.	16"	6'-0"	#3@10"o.c.	16.16
10'	12'-0"	6"	#4@24"o.c.	#4@48"o.c.	16"x16"	2-#7 EF	—	#2@12"o.c.	24"	8'-0"	#3@12"o.c.	35.53
15'	10'-8"	6"	#4@24"o.c.	#4@48"o.c.	22"x16"	2-#7 EF	—	#2@12"o.c.	30"	10'-0"	#3@12"o.c.	60.37
20'	8'-0"	6"	#4@24"o.c.	#4@48"o.c.	22"x16"	2-#7 EF	1-#7 EF	2-#2@12"o.c.	30"	11'-0"	#3@12"o.c.	71.07
40#/ϕ wind load												
5'	10'-8"	6"	#4@24"o.c.	#4@48"o.c.	14"x16"	2-#5 EF	—	#2@12"o.c.	16"	6'-0"	#3@10"o.c.	18.57
10'	10'-8"	6"	#4@24"o.c.	#4@48"o.c.	18"x16"	2-#7 EF	—	#2@12"o.c.	24"	9'-0"	#3@12"o.c.	38.41
15'	8'-0"	6"	#4@24"o.c.	#4@48"o.c.	22"x16"	2-#7 EF	—	#2@12"o.c.	30"	10'-0"	#3@12"o.c.	67.62
20'	6'-0"	6"	#4@24"o.c.	#4@48"o.c.	22"x16"	2-#7 EF	1-#7 EF	2-#2@12"o.c.	30"	12'-0"	#3@12"o.c.	76.82

See sheet M-2 for General notes and details

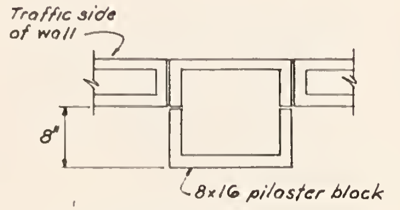
M

ACOUSTIC BARRIER
MASONRY WALL

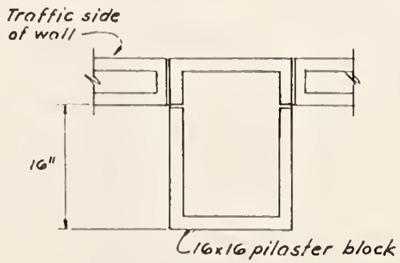
M-1



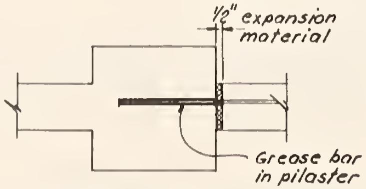
10x16 COLUMN PLAN DETAIL



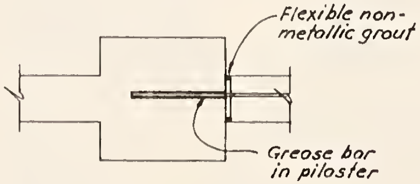
14x16 COLUMN PLAN DETAIL



22x16 COLUMN PLAN DETAIL



EXPANSION JOINT DETAIL



CONTRACTION JOINT DETAIL

GENERAL NOTES:

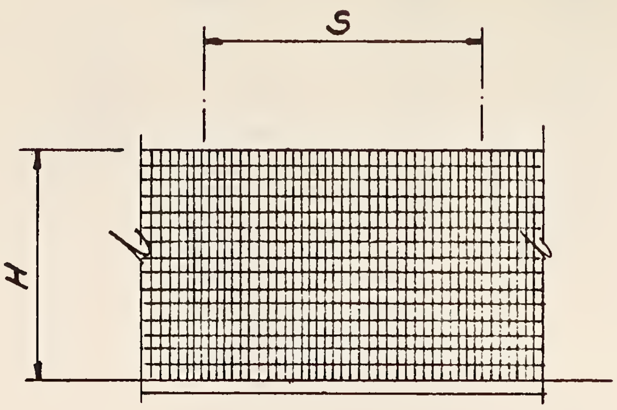
1. GENERAL.
   a. Height of barrier shall be based on acoustic requirements.
   b. Barrier walls having a height (H) not indicated in the tables shall be constructed as shown in the next higher height category.
   c. Cost factor column indicated relative cost per lineal foot of acoustic barrier.
2. MASONRY WALLS.
   a. Wall blocks shall be manufactured to comply with the requirements of ASTM C90 for grade U hollow load bearing concrete units with compressive strength f'm = 2500 lbs. per sq. in. Grouted allowable stress f'm = 400 lbs. per sq. in. without inspection.
   b. Reinforcing in walls shall comply with ASTM A615 grade 40.
   c. The grout shall be portland cement mortar type M.
   d. Expansion or contraction joints as shown shall be placed at the end of walls at the pilaster face as required by climatic and other local conditions.
3. MASONRY COLUMNS.
   a. The hollow block and reinforcing shall comply with the same ASTM controls as the walls.
   b. The concrete fill in the column core shall be concrete having a min. compressive strength of 3000 lbs. per sq. in. at 28 days.
4. PIERS.
   a. The piers shall be of concrete having a compressive strength of 3000 lbs. per sq. in. at 28 days.
   b. The dowel reinforcing shall match the column steel in size and spacing and shall project out of the pier 48 bar diameters.
   c. Dowels and ties shall comply with ASTM A615 for grade 40 reinforcing.
   d. Concrete shall be placed in drilled piers utilizing the earth as a form.
5. FOUNDATIONS.
   a. The drilled piers have been designed utilizing an allowable passive pressure of 300 lbs. per sq. ft. and using the following formula: $D = \left(\frac{14.52\,M}{pd}\right)^{1/3}$

      M = Moment at top of drilled pier (ft. lbs.)
      p = Allowable passive pressure (300 lbs. per sq. ft.)
      d = Diameter of pier (ft.)
      D = Depth of pier (ft.)

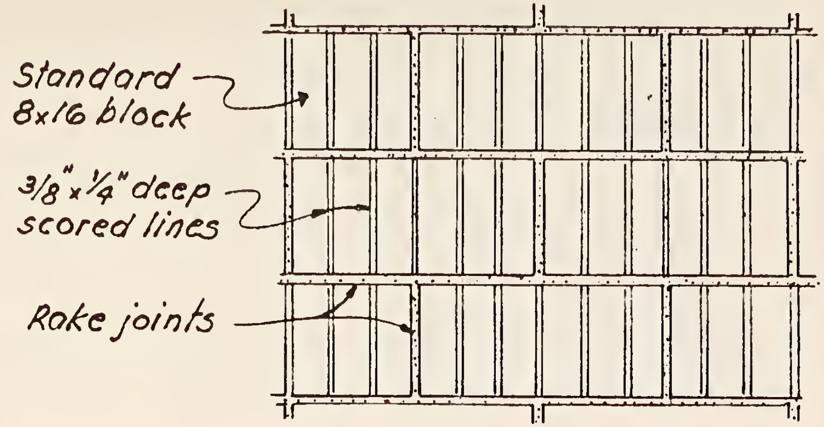
      Note that depth of pier (D) shall be measured from the top of soil level capable of providing lateral support.
6. ADAPTATIONS.
   a. Where it is desired to use smaller columns, or longer bays. Continuous inspection will permit 100% increases in the concrete block allowable working stress.
   b. Since the concrete block construction requires a rectilinear panel, on a slight grade the top and/or bottom courses may be poured concrete of the appropriate course height.

ACOUSTIC BARRIER
MASONRY WALL

M-2



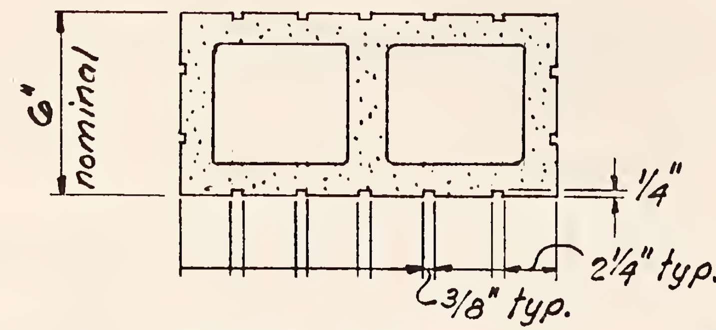
ELEVATION



PARTIAL ELEVATION

Notes:

1. All notes on sheet M-2 apply to this drawing.
2. The cost factor for the scored block wall is added to the cost of the basic structure. See schedule below.



BLOCK PLAN

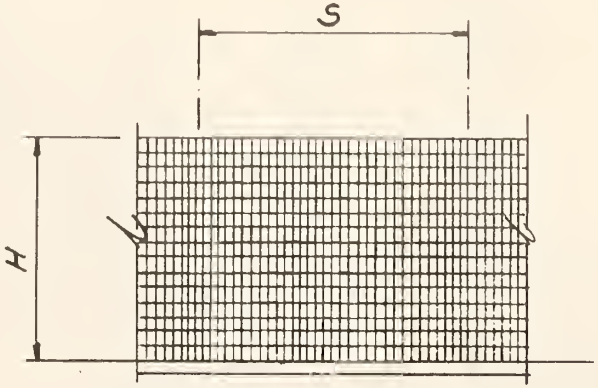
SCHEDULE

H	Vertical Scored Block	Integral Color Block	Paint one side
5'	2.59	2.36	1.27
10'	5.18	4.72	2.53
15'	7.76	7.07	3.80
20'	10.35	9.43	5.06

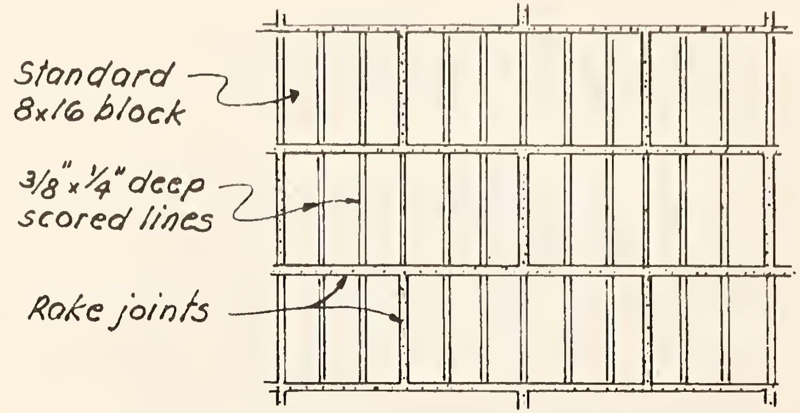
M-3

ACOUSTIC BARRIER
CONCRETE MASONRY UNITS
VERTICAL SCORED BLOCK

M-1 6 7



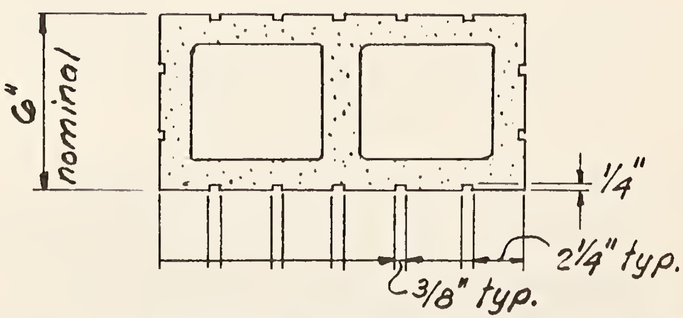
ELEVATION



PARTIAL ELEVATION

Notes:

1. All notes on sheet M-2 apply to this drawing.
2. The cost factor for the scored block wall is added to the cost of the basic structure. See schedule below.



BLOCK PLAN

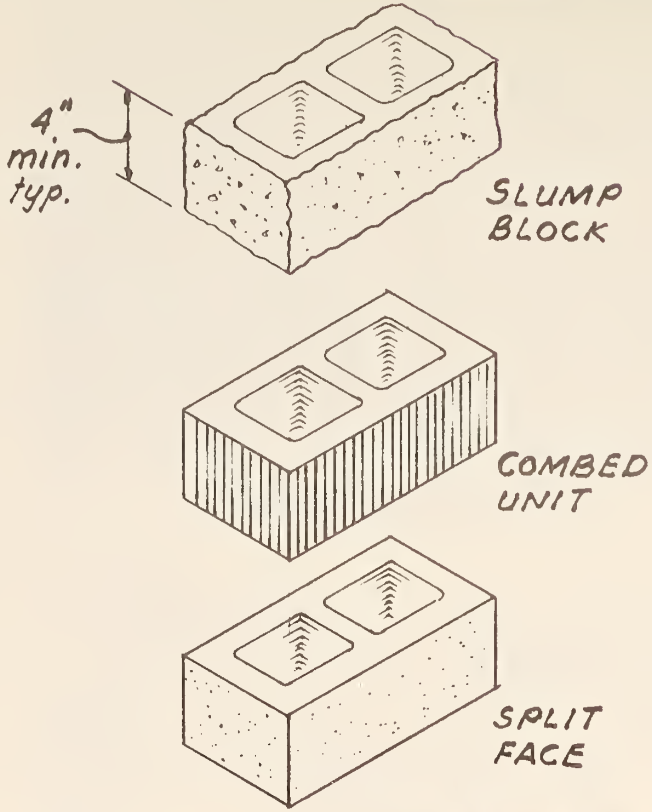
SCHEDULE

H	Vertical Scored Block	Integral Color Block	Paint One Side
5'	2.59	2.36	1.27
10'	5.18	4.72	2.53
15'	7.76	7.07	3.80
20'	10.35	9.43	5.06

M-1 6 7

M-3

ACOUSTIC BARRIER
CONCRETE MASONRY UNITS
VERTICAL SCORED BLOCK



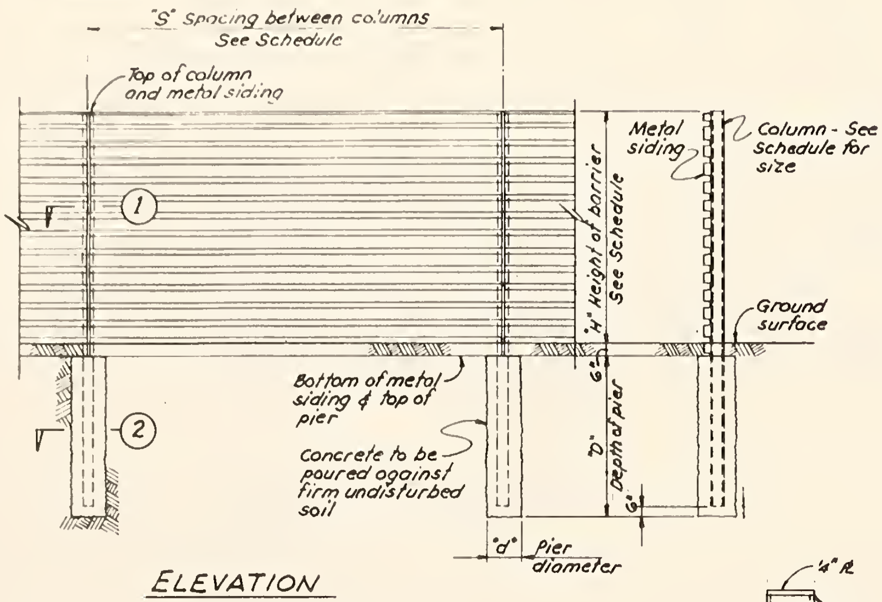
1. All notes on sheet M-2 apply to this drawing.
2. The cost factor for alternate blocks and finishes is stated on a lineal foot basis and is to be added to the cost of the basic structure. See schedule below.

SCHEDULE

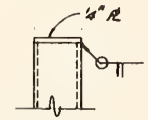
Height	6" slump block	4" slump block	combed units	split face	Integral color	paint 1-side
5'	12.95	11.50	2.59	11.50	2.36	1.27
10'	25.88	23.00	5.18	23.00	4.72	2.53
15'	38.81	34.50	7.76	34.50	7.07	3.80
20'	51.75	46.00	10.35	45.00	9.43	5.06
	M-2	**3**	**4**	**5**	**6**	**7**

M·4

ACOUSTIC BARRIER
CONCRETE MASONRY UNITS
ALTERNATE BLOCK TYPES



ELEVATION

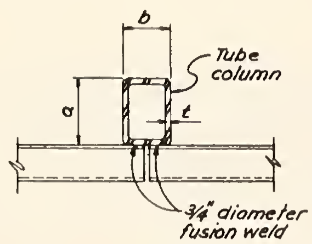


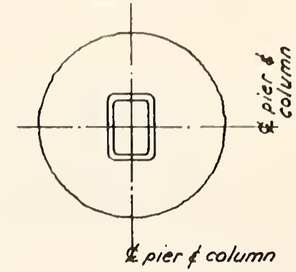
COLUMN CAP DETAIL

SCHEDULE

20#/' horizontal loading							
H	S	D	d	col. size (a x b x t)	Basic cost factor	Painting cost factor	Weathering steel cost factor
5'	18'-0"	6'-0"	1'-0"	4x3x1/4	28.52	.86	1.27
10'	18'-0"	8'-6"	1'-6"	6x4x3/8	69.00	1.73	2.53
15'	18'-0"	10'-0"	2'-0"	10x4x3/8	113.16	2.59	3.80
20'	18'-0"	12'-0"	2'-0"	12x6x3/8	174.80	3.45	5.06
30#/' horizontal loading							
H	S	D	d	col. size (a x b x t)	Basic cost factor	Painting cost factor	Weathering steel cost factor
5'	16'-0"	7'-0"	1'-0"	4x3x1/4	34.56	.86	1.27
10'	16'-0"	9'-5"	1'-6"	8x4x5/16	77.28	1.73	2.53
15'	16'-0"	11'-0"	2'-0"	12x6x5/16	129.38	2.59	3.80
20'	16'-0"	12'-6"	2'-6"	12x8x1/2	223.10	3.45	5.06
40#/' horizontal loading							
H	S	D	d	col. size (a x b x t)	Basic cost factor	Painting cost factor	Weathering steel cost factor
5'	14'-0"	6'-6"	1'-6"	5x3x1/4	34.16	.86	1.27
10'	14'-0"	10'-0"	1'-6"	8x4x3/8	78.43	1.73	2.53
15'	14'-0"	11'-6"	2'-0"	12x6x3/8	146.63	2.59	3.80
20'	14'-0"	13'-0"	2'-6"	12x8x1/2	253.00	3.45	5.06

S- 4 5



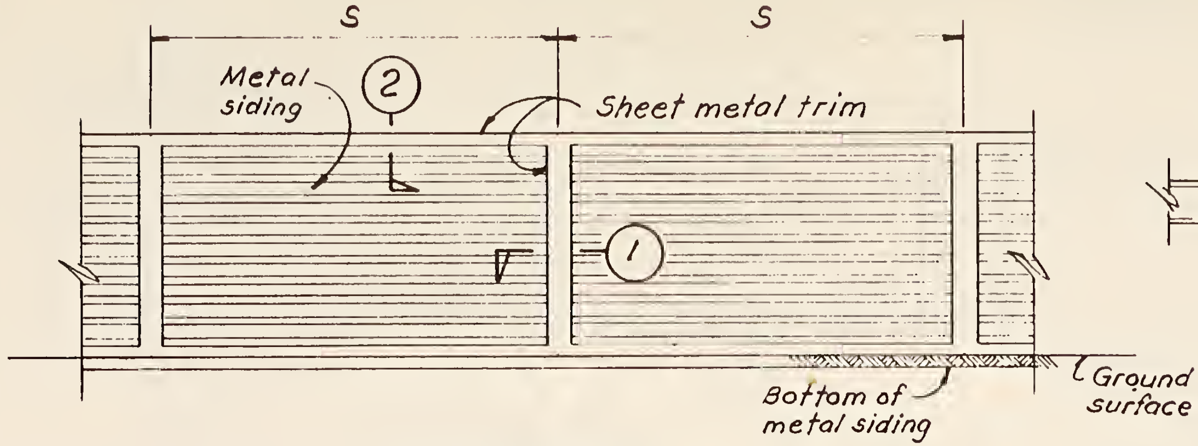


NOTES: SECTION 1 SECTION 2

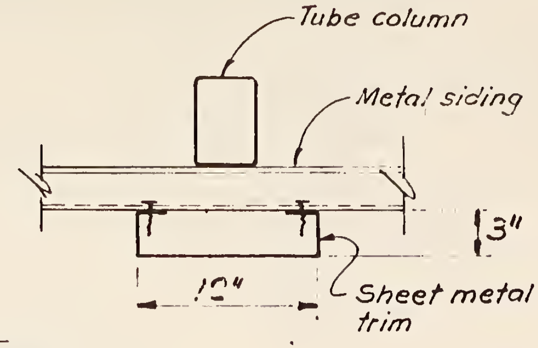
1. GENERAL
   a. Height of barrier shall be based on acoustic requirements.
   b. Barrier walls having a height (H) not indicated in the tables shall be constructed as shown in the next higher height category.
   c. Cost factor column indicates relative cost per lineal foot of acoustic barrier.
2. METAL SIDING
   a. Metal siding shall be galvanized 16 ga. steel conforming to ASTM Specification A446.
   b. Metal siding shall span horizontally between columns. Siding shall consist of 3" deep units with flutes spaced not more than 8" on center and provided with interlocking side laps. A 12" wide segment shall have a minimum section modulus of 0.98 in.^{3}; a moment of inertia of 1.70 in.^{4}; and a minimum weight of 4 lbs. per square foot.
   c. Siding shall be attached to the column with 3/4" diameter fusion welds with a minimum of 3 welds per unit. Side joints shall be clinched at 3'-0" maximum centers.
   d. All welds shall be touched-up with zinc rich primer.
3. COLUMNS
   a. Columns shall be structural tubing conforming to ASTM Specification A501 having a yield stress of 36,000 lbs. per sq. in.
   b. Exposed portions of columns shall be galvanized.
4. CONCRETE
   a. Concrete in piers shall have a 28 day compressive strength of 2500 lbs. per sq. in.
   b. Concrete shall be spaced in drilled piers utilizing the earth as a form.
5. FOUNDATIONS
   a. The drilled piers have been designed utilizing an allowable passive pressure of 300 lbs. per square foot and the following formula: $D = \left(\frac{14.52\,M}{pd}\right)^{1/3}$

      M = Moment at top of drilled pier (ft. lbs.)
      p = Allowable passive pressure (300 lbs. per sq. ft.)
      d = Diameter of pier (ft.)
      D = Depth of pier (ft.)
6. Alternate No. 1 (painting). Alternate No. 1 shall include the basic structure shown on this drawing with the addition of painting one side of the structure. Painting shall include one coat Pre-Treatment, Vinyl Wash Primer and one finish coat. The painting cost factor shown in the schedule is on a lineal foot basis and is added to the basic cost to determine the total cost. Painting both sides of the barrier would increase the cost almost doubling it.
7. Alternate No. 2 (weathering steel). Alternate No 2 requires all steel to be unpainted weathering steel. This shall include metal siding and columns. The cost factor indicated in the schedule represents the increased cost per lineal foot of installed barrier.

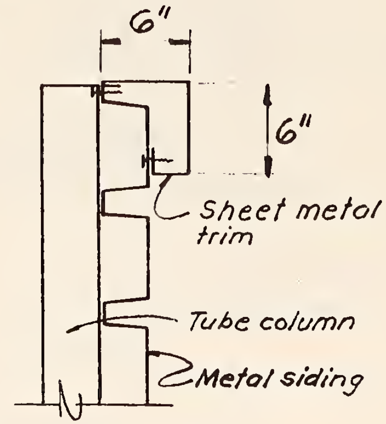
ACOUSTIC BARRIER STEEL	S-1



ELEVATION



SECTION 1



SECTION 2

NOTES:

1. All notes on sheet S-1 apply to this drawing.
2. Sheet metal trim to be 20 ga. galv. steel, attached to metal siding with self-drilling screws, #10-16x3/4" spaced at 16" o.c. horiz. and vert.
3. The cost factor for the sheet metal trim is stated on a lineal foot basis and is added to the basic cost of the structure to arrive at a total cost. See schedule below.

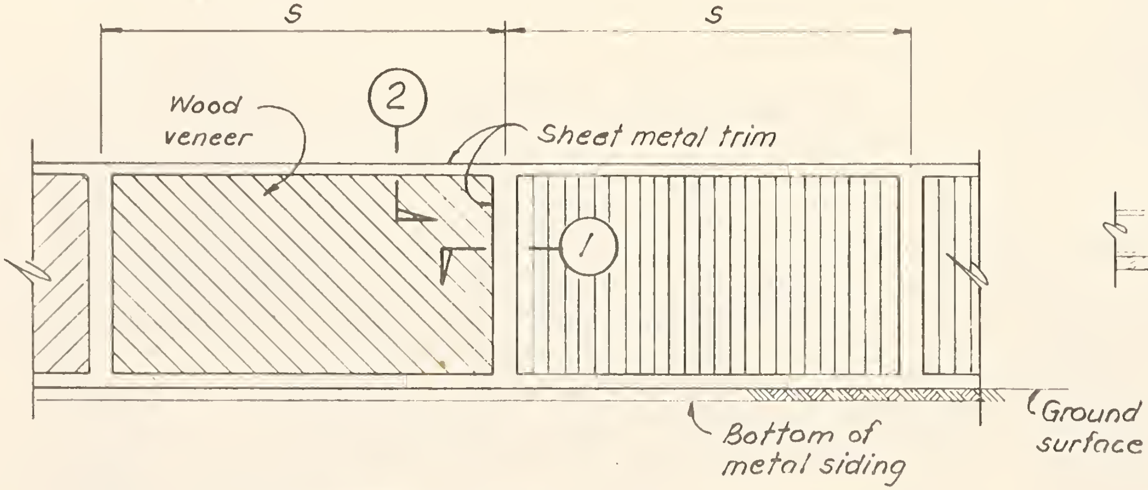
SCHEDULE

H	Cost factor
5'	2.30
10'	4.60
15'	6.90
20'	9.20

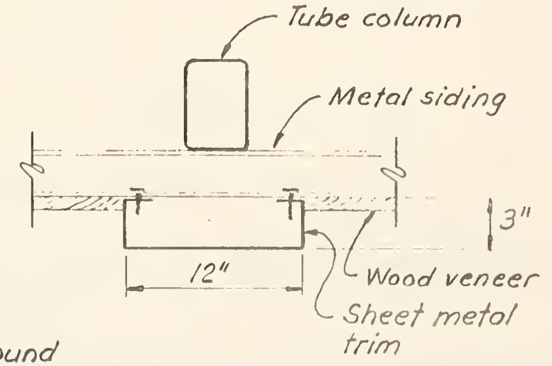
S-1

S-2

STEEL ACOUSTIC BARRIER
W/ SHEET METAL TRIM



ELEVATION

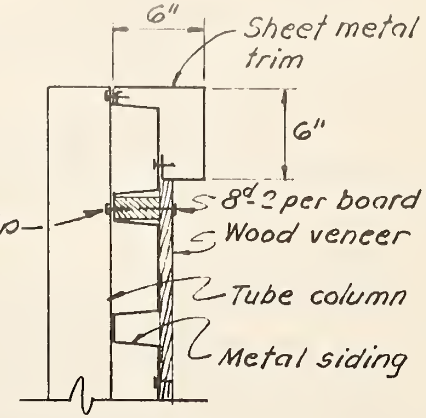


SECTION 1

1. All notes, except notes no. 6 & 7 on sheet S-1 apply to this drawing.
2. See note no. 2 on sheet S-2 for sheet metal trim.
3. 2x3 nailing strips shall be continuous and spaced at 16" o.c. horiz. 2x3 shall be net size douglas fir no. 2 as per grading rules of the WCLIB. 2x3 to be attached to metal siding with self-drilled screws, #14-10x3/4" @ 16" o.c.
4. Wood veneer to be 1x8 cedar utility grade or better as per grading rules of the WWPA. Wood veneer to be nailed to 2x3 with 8^d-2 per board @ 16" o.c. horiz.
5. Wood veneer shall be stained with 2 coats of semi-transparent stain.
6. **The cost** factor for the sheet metal trim, 2x3 nailing strips, wood **veneer** and stain is stated on a lineal foot basis and is added **to the basic** structure to arrive at a total cost. See schedule below.

SCHEDULE

H	Cost factor
5'	5.41
10'	10.81
15'	16.22
20'	21.62

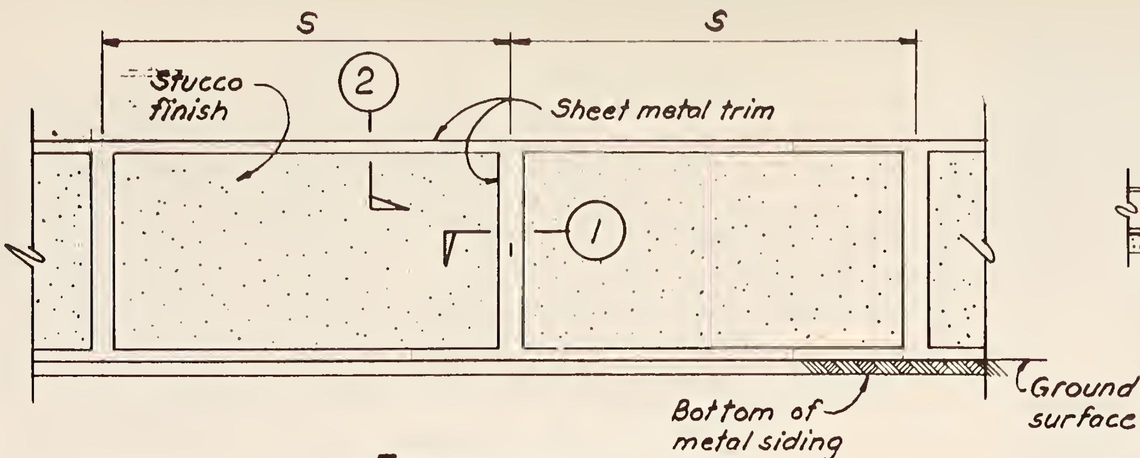


SECTION 2

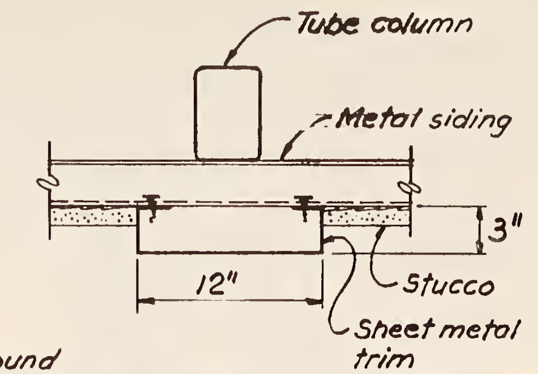
S-3

STEEL ACOUSTIC BARRIER
W/SHEET METAL TRIM & WOOD VENEER

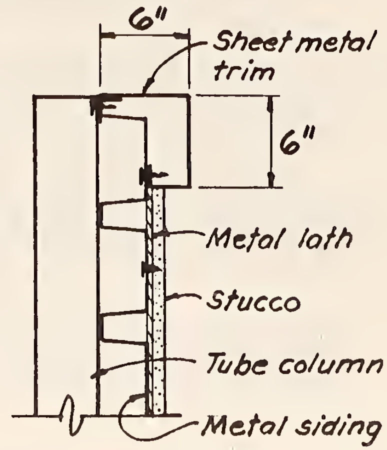
S-2



ELEVATION



SECTION 1



SECTION 2

NOTES:

1. All notes, except notes no 6 & 7, on sheet S-1 apply to this drawing.
2. See note no. 2 on sheet S-2 for sheet metal trim.
3. Metal lath shall conform to the applicable requirements of specification QQ-B-101 type F or SF. Metal lath shall be tack welded to metal siding at 16" o.c. staggered on each rib.
4. Portland cement for stucco shall conform to ASTM designations C150 type I, C 206 type S, C91 & C144.
5. Painting of sheet metal trim shall include one coat pre-treatment, Vinyl Wash Primer and one finish coat.
6. Painting of stucco shall include 2 coats of Vinyl-acrylic emulsion paint.
7. The cost factor for the sheet metal trim, metal lath, stucco and paint is stated on a lineal foot basis and is added to the basic cost of of the structure to arrive at the total cost. See schedule below.

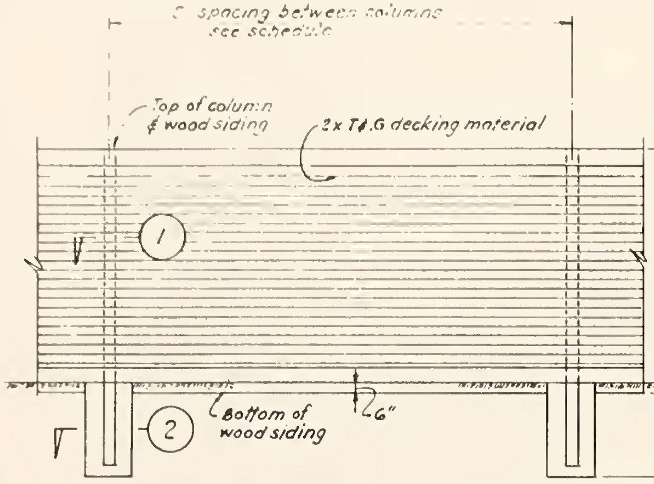
SCHEDULE

H	Cost factor
5'	8.05
10'	16.10
15'	24.15
20'	32.20

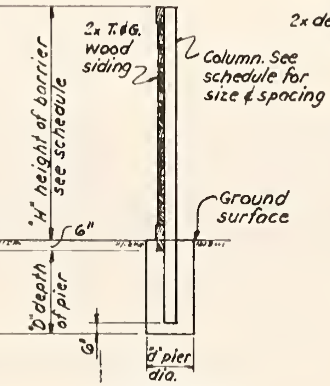
S-4

STEEL ACOUSTIC BARRIER
W/SHEET METAL TRIM & STUCCO

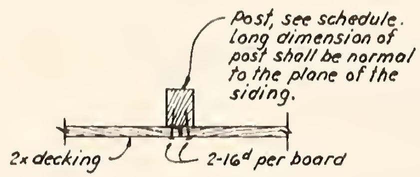
S-3



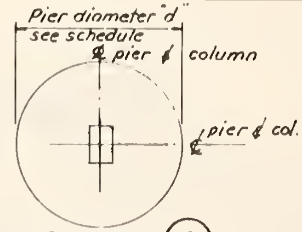
ELEVATION



SECTION



SECTION (1)



SECTION (2)

SCHEDULE

H	S	D	d	Post size	Basic Cost Factor	Pressure Treating Cost Factor	Paint Cost Factor	Stain Cost Factor
20#/¢ horizontal loading								
5'	10'	5'	12"	4x6	14.26	1.05	1.15	.86
10'	10'	7'	18"	6x10	34.73	2.45	2.30	1.76
15'	10'	8.5'	24"	6x14	56.75	3.51	3.45	2.59
20'	10'	9.5'	30"	8x16	87.63	5.11	4.60	3.45
30#/¢ horizontal loading								
5'	8'	5.5'	12"	4x8	17.08	1.31	1.15	.86
10'	8'	7.5'	18"	6x10	38.64	2.60	2.30	1.76
15'	8'	9.0'	24"	6x16	64.69	3.84	3.45	2.59
20'	6'	9.0'	30"	8x16	111.55	6.10	4.60	3.45
40#/¢ horizontal loading								
5'	8'	6'	12"	4x8	17.14	1.31	1.15	.86
10'	8'	8'	18"	6x12	39.22	2.75	2.30	1.76
15'	8'	10'	24"	8x16	73.83	4.21	3.45	2.59
20'	6'	10'	30"	10x16	126.27	6.72	4.60	3.45

Note that depth D shall be measured from the top of soil level capable of providing lateral support.

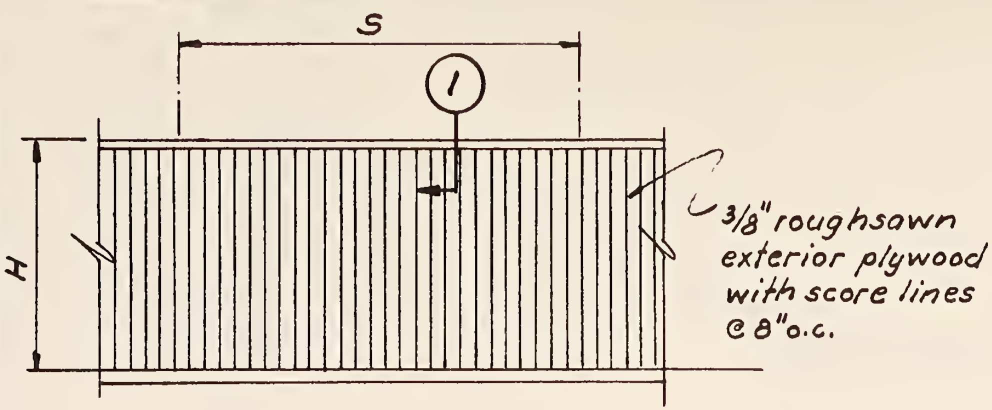
W- 3 4 5

NOTES:

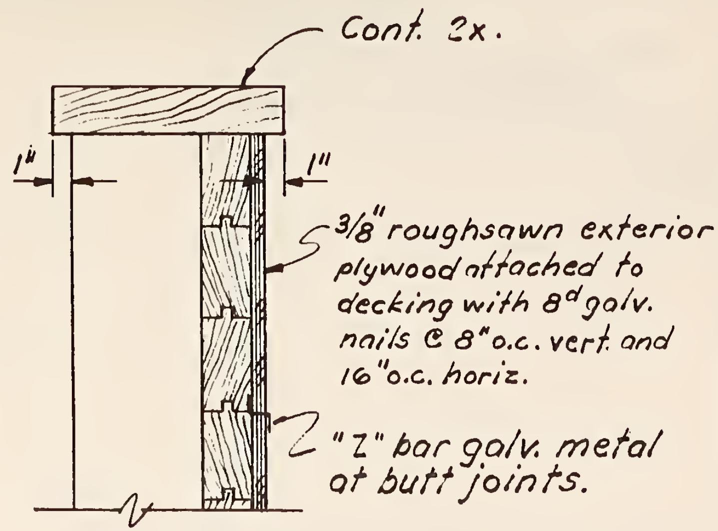
1. GENERAL.
   a. Height of barrier shall be based on acoustic requirements.
   b. Barrier walls having a height (H) not indicated in the tables shall be constructed as shown in the next higher height category.
   c. Cost factor column indicates relative cost per lineal foot of acoustic barrier.
2. SIDING.
   a. 2x wood decking material shall be utilized to span horizontally between posts. Design criteria is based on an allowable bending stress of 1400 lbs. per sq. in. and a 33⅓ % increase in stress for wind loads is considered appropriate. Decking shall be MC15.
   b. Siding in contact with the ground and for a distance of 6" above grade shall be treated with wood preservative.
3. POSTS.
   a. Wood post shall be utilized at the spacing indicated on the schedule. Design criteria is based on an allowable bending stress of 1400 lbs. per sq. in. with a 33⅓ % increase for wind loadings.
   b. Posts embedded in concrete shall be treated with a wood preservative in the area of embedment and 12" above grade.
4. CONCRETE.
   a. Concrete in the piers shall have a 28 day compressive strength of 2500 lbs. per sq. in.
   b. Concrete shall be placed in drilled piers utilizing the earth as the forms.
5. FOUNDATIONS.
   a. The drilled piers have been designed utilizing an allowable passive pressure of 300 lbs. per sq. ft. and the following formula: $D = \left(\frac{14.52\,M}{pd}\right)^{1/3}$

      M = Moment at top of drilled pier (ft. lbs.)
      p = Allowable passive pressure (300 lbs. per sq. ft.)
      d = Diameter of pier (ft.)
      D = Depth of pier (ft.)
6. ALTERNATE #1 (Preservative Treatment). Alternate #1 represents the additional cost factor for treating the basic wood structure indicated on this reference plan. The necessity for treatment and the type of preservative will be subject to local conditions. All treatment shall conform to AWPA Standard C-14.
7. ALTERNATE #2 (Painting). Alternate #2 represents the additional cost factor required to paint one side of the basic wood structure shown on this reference plan. Painting shall consist of 3 applications of paint. 2 coats of latex base paint conforming to Federal Specification TT-P-0096B shall be applied over a primer coat conforming to Federal Specification TT-P-0025D.
8. ALTERNATE #3 (Staining) Alternate #3 represents the additional cost factor required to stain one side of the basic wood structure. Stain shall consist of 2 coats of semi-transparent sealer/stain applied in accordance with manufacturers written instructions.

ACOUSTIC BARRIER WOOD	W-1



ELEVATION



SECTION 1

Notes:
1. All notes on sheet W-1 apply to this drawing.
2. The cost factor for the plywood is stated on a lineal foot basis and is added to the basic structure to arrive at a total cost.

SCHEDULE

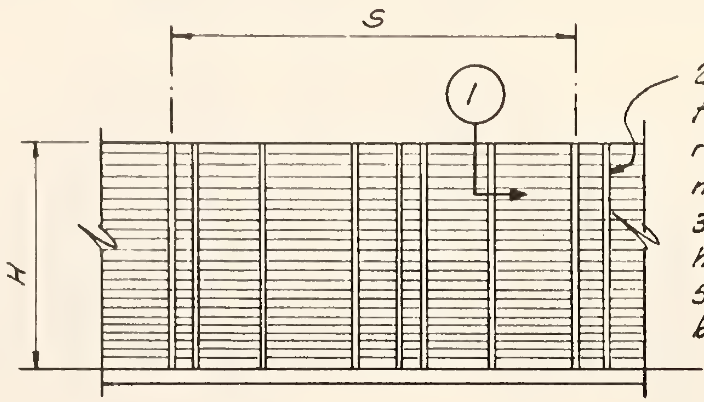
H	Plywood Facing	Paint	Stain
5'	2.93	1.15	.86
10'	5.87	2.30	1.73
15'	8.80	3.45	2.59
20'	11.73	4.60	3.45

W-1 4 5

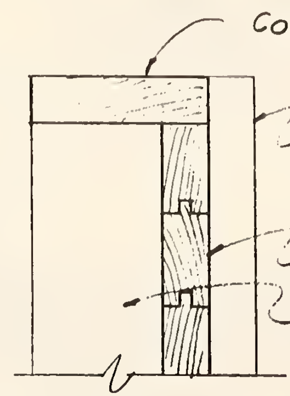
W-2

ACOUSTIC BARRIER
WOOD WITH PLYWOOD
FACING

2



ELEVATION



SECTION 1

Notes:
1. All notes on sheet W-1 apply to this drawing
2. The cost factor for the vertical battens is stated on a lineal foot basis and is added to the basic structure to arrive at a total cost.

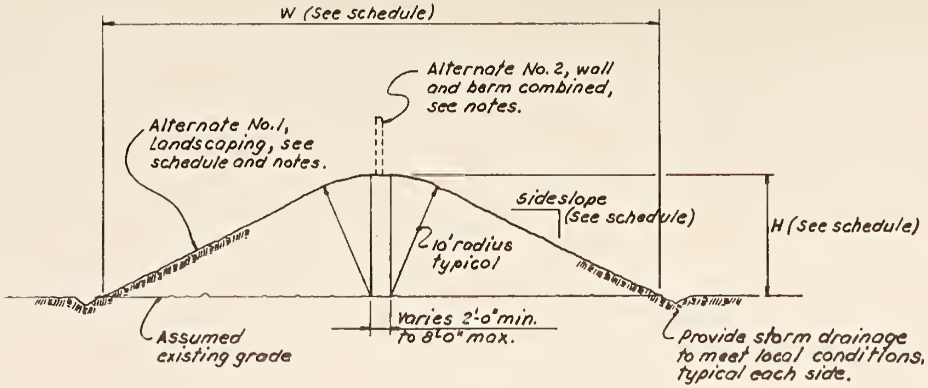
SCHEDULE

H	Cost Factor One Side Only
5'	.64
10'	1.29
15'	2.59
20'	3.45

W-2

W-3

ACOUSTIC BARRIER
WOOD WITH VERTICAL
BATTENS



SCHEDULE

4:1 Slope				B(4)-	1
H	W	Cu. yds per L.F.	Sq. ft. per L.F.	Basic cost factor	Landscape cost factor
5'	48'	5.2	49	5.85	28.18
10'	88'	17.8	91	20.16	52.33
15'	128'	37.8	132	43.47	75.90
20'	168'	65.2	173	78.73	99.48

3:1 Slope				B(3)-	1
H	W	Cu. yds. per L.F.	Sq. ft. per L.F.	Basic cost factor	Landscape cost factor
5'	38	4.3	41	4.84	23.58
10'	68	14.1	73	15.88	41.98
15'	98	29.4	105	33.81	60.38
20'	128	50.0	137	60.38	78.78

2:1 Slope				B(2)-	1
H	W	Cu. yds per L.F.	Sq. ft. per L.F.	Basic cost factor	Landscape cost factor
6'	28	3.3	32	3.71	18.40
10'	48	10.4	54	11.72	31.05
15'	68	21.1	77	24.27	44.28
20'	88	35.6	99	42.99	56.93

NOTES:

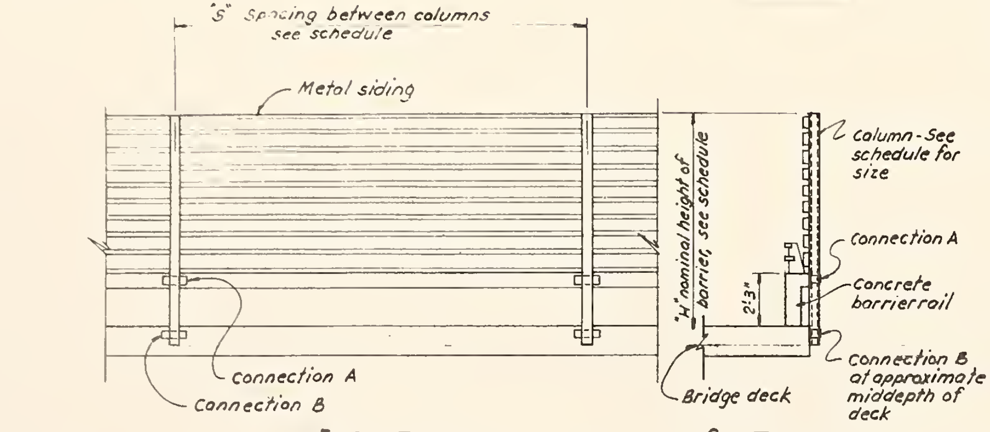
1. GENERAL:
   a. Height of barrier to be selected based on acoustic considerations.
   b. Cost factor column indicates relative cost per lineal foot of berm.
   c. Storm drainage to be designed for local conditions (not included in relative cost factor).
   d. Due to local conditions, cost of fill may vary considerably.
   e. Berm indicated is basic profile. Due to location conditions and visual considerations, it may be desirable to vary the height and sideslopes of the berm.
2. EARTHMOUND GRADING:
   a. Grading criteria to be based on site specific soils and geologic investigation.
3. ALTERNATE NO 1.
   a. Landscape Alternate No. 1 shall include basic berm plus automatic irrigation, soil preparation, hydromulch planting of ground cover, tree planting at an average density of 1-#5 gallon tree per 1600 sq. ft. one 1 gallon shrubs per 200 sq. ft. Cost factor for landscaping is added to the basic cost factor to determine total cost.
4. ALTERNATE NO. 2, WALL AND BERM COMBINED.
   a. The relative cost factor for Alternate No. 2, berm and wall combined, is determined by adding wall cost factor for wall selected to berm cost factor plus landscape cost factor.

ACOUSTIC BARRIER
EARTH BERM

B-1

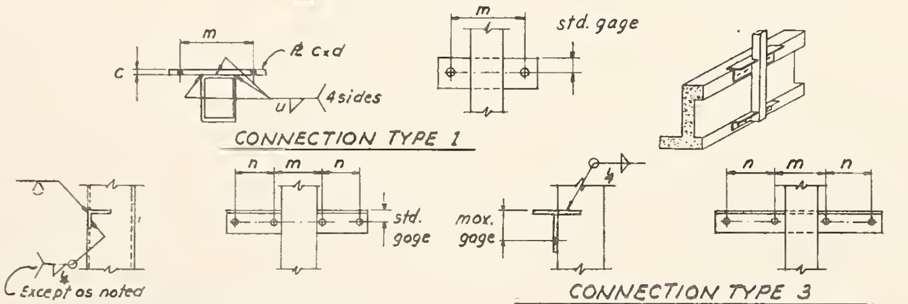
APPENDIX B

REFERENCE DRAWINGS FOR BARRIERS ON ELEVATED STRUCTURES



ELEVATION

SECTION



CONNECTION TYPE 1

CONNECTION TYPE 2

CONNECTION TYPE 3

NOTES:

1. GENERAL.
   a. Height of barrier shall be based on acoustic requirements.
   b. Barrier walls having a height (H) not indicated in the tables shall be constructed as shown in the next higher height category.
   c. Cost factor column indicates relative cost per lineal foot of acoustic barrier.
2. METAL SIDING.
   a. Metal siding shall be galvanized 16 ga. steel conforming to ASTM Specification A446.
   b. Metal siding shall span horizontally between columns. Siding shall consist of 3" deep units with flutes spaced not more than 8" o.c. and provided with interlocking side laps. A 12" wide segment shall have a minimum section modulus of 0.98 in.^{3}; a moment of inertia of 1.70 in.^{4}; and a minimum weight of 4 lbs. per sq. ft.
   c. Siding shall be attached to the column with 3/4" diameter fusion welds with a minimum of 3 welds per unit. Side joints shall be clinched at 3'-0" maximum centers.
   d. All welds shall be touched up with zinc rich primer.
3. COLUMNS.
   a. Columns shall be structural tubing conforming to ASTM Specification A 501 having a yield stress of 36,000 lbs. per sq. in.
   b. Exposed portions of column shall be galvanized.
4. CONNECTIONS.
   a. All steel shapes and plates shall conform to ASTM Specification A36 having a yield stress of 36,000 lbs. per sq. in.
   b. Anchor bolts shall conform to ASTM A307 and galvanizing shall conform to class D material of ASTM Specification A 153.
5. DESIGN CRITERIA.
   a. Maximum allowable load on concrete barrier rail from wind load is equal to 10^K max. highway barrier impact load. Therefore this schedule may be used with existing bridge structures.
   b. Acoustic barrier material used is the same steel system indicated on sheet S-1 with siding only above the barrier rail. Connection details, etc. shown on sheet S-1 apply to this sheet as appropriate.
   c. The spacing module "S" on this sheet is based on the module of the standard steel system on sheet S-1.
   d. Low dead load of the steel system was considered to be the primary reason for using this system as an example of one which may be placed on safe existing bridges without overloading.
6. ADAPTATIONS.
   a. Similar details may be developed with other acoustical barrier media.
   b. Where new structures are involved, the deck and barrier rail can be designed for governing wind loads and barrier dead load criteria.
   c. Bolt values used are U.B.C. uninspected connections. As appropriate under heavier and/or high loadings, standard bolt values are subject to 100% increase under special inspection. In addition, patented anchor bolts may be used which have greater allowable capabilities.

SCHEDULE

H	S	Tube Col. a x b x t	Connection "A" Type	Bolts	m	n	c x d x u	Connection "B" Type	Bolts	m	c x d x u	Basic Cost Factor	Paint Cost Factor	Weathering Steel Cost Factor
20#/φ horizontal loading														
5'	18'-0"	4x3x1/4	1	2-1/2"φ	@6 1/2" o.c.	—	PL 3/8x3x1/4	1	2-1/2"φ	@6 1/2" o.c.	PL 3/8x3x1/4	16.68	.86	1.27
10'	18'-0"	6x4x3/8	1	2-7/8"φ	@9" o.c.	—	PL 5/8x4x1/2	1	2-3/4"φ	@7 1/2" o.c.	PL 3/8x4x1/2	27.14	1.73	2.53
15'	9'-0"	8x3x5/16	2	4-3/4"φ	@6" o.c.	@6" o.c.	L 3x3x1/4	2	2-3/4"φ	@8" o.c.	L 3x3x1/4	43.64	2.59	3.80
20'	9'-0"	12x4x1/4	Loads too high for standard bolting									69.46	3.45	5.06
30#/φ horizontal loading														
5'	16'-0"	4x3x1/4	1	2-1/2"φ	@6 1/2" o.c.	—	PL 3/8x3x1/4	1	2-1/2"φ	@6 1/2" o.c.	PL 3/8x3x1/4	17.83	.86	1.27
10'	16'-0"	8x4x5/16	2	4-7/8"φ	@7" o.c.	@6 1/2" o.c.	L 3x3x1/4	1	2-7/8"φ	@7 5/8" o.c.	PL 1/2x4x3/8	30.82	1.73	2.53
15'	8'-0"	10x4x1/4	3	4-7/8"φ	@6 1/2" o.c.	@6 1/2" o.c.	WT 6x13.5	2	2-7/8"φ	@8 3/4" o.c.	L 3x3x1/4	48.30	2.59	3.80
20'	8'-0"	12x6x5/16	Loads too high for standard bolting									76.36	3.45	5.06
40#/φ horizontal loading														
5'	14'-0"	5x3x1/4	1	2-1/2"φ	@6 1/2" o.c.		PL 3/8x3x1/4	1	2-1/2"φ	@6 1/2" o.c.	PL 3/8x8x1/4	19.55	.86	1.27
10'	14'-0"	8x4x3/8	3	4-7/8"φ	@7 1/2" o.c.	@7 1/2" o.c.	WT 6x13.5	2	2-7/8"φ	@9" o.c.	L 3x3x1/4	33.01	1.73	2.53
15'	7'-0"	10x4x5/16	3	4-7/8"φ	@7 1/2" o.c.	@7 1/2" o.c.	WT 6x13.5	2	2-7/8"φ	@10" o.c.	L 3 1/2x3 1/2x1/4	65.90	2.59	3.80
20'	7'-0"	12x6x5/16	Loads too high for standard bolting									96.60	3.45	5.06

Bolt capacity chart - uninspected

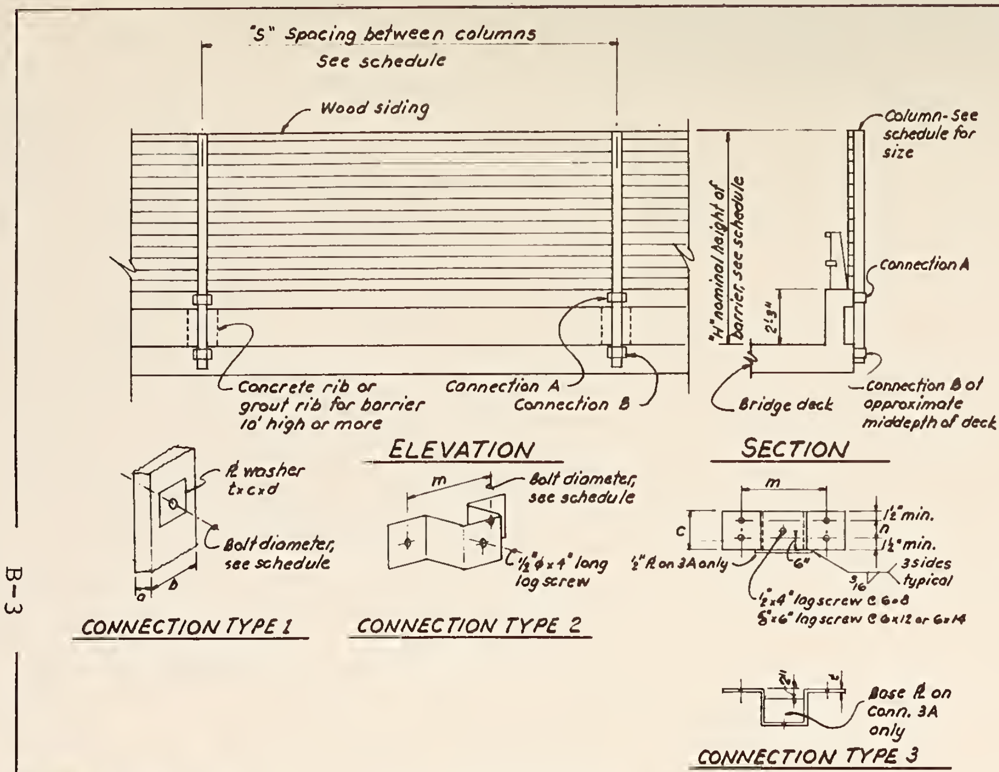
Bolt dia.	Embed	Shear cap.#	Tension cap.#
1/2"	4"	1000	950
5/8"	4"	1500	1500
3/4"	5"	1780	2250
7/8"	6"	2075	3200
1"	7"	2075	3200

Bolt capacity in chart based on 12 diameter spacing (min)

ACOUSTIC BARRIER STEEL ON ELEVATED STRUCTURE

ES-1

ES- 1 2



NOTES:

1. GENERAL:
   a. Height of barrier shall be based on acoustic requirements
   b. Barrier walls having a height (H) not indicated in the tables shall be constructed as shown in the next higher height category.
   c. cost factor column indicates relative cost per lineal foot.
2. SIDING.
   a. 2x wood decking material shall be utilized to span horizontally between posts. Design criteria is based on an allowable bending stress of 1400 lbs. per sq. in. with a 33⅓ % increase for wind loading. Decking shall be MC15.
3. POSTS.
   a. Wood posts shall be utilized at the spacing indicated on the schedule. Design criteria is based on an allowable bending stress of 1400 lbs. per sq. in. with a 33⅓ % increase for wind loading.
4. CONNECTIONS.
   a. All steel shapes and plates shall conform to ASTM Specification A36 having a yeild stress of 36,000 lbs. per sq. in.
   b. Anchor bolts shall conform to ASTM A307 and galvanizing shall conform to ASTM Specification A153.
5. DESIGN CRITERIA.
   a. Maximum allowable load on concrete barrier rail from wind load is equal to HS 20 max. highway barrier impact load. Therefore this schedule may be used with existing bridge structures.
   b. Acoustic barrier material used is the same wood system indicated on Sheet W1 with siding only above the barrier rail. Connection details etc. as shown on sheet W-1 apply to this sheet as appropriate.
   c. The spacing module "S" on this sheet is based on the module of wood systems shown on sheet W-1.
6. ALTERNATE #1. (Preservative Treatment). Alternate #1 represents the additional cost factor for treating the basic wood structure indicated on this reference plan. The necessity for treatment and the type of preservative will be subject to local conditions. All treatment shall conform to AWPA standard C-14.
7. ALTERNATE #2 (Painting) Alternate #2 represents the additional cost factor required to paint one side of the basic wood structure shown on this reference plan. Painting shall consist of 3 applications of paint. 2 coats of latex base paint conforming to Federal Specification TT-P-0096B shall be applied over a primer coat conforming to Federal Specification TT-P-0025D.
8. ALTERNATE #3 (Staining) Alternate #3 represents the additional cost factor required to stain one side of the basic wood structure. Stain shall consist of 2 coats of semi-transparent sealer/stain applied in accordance with manufacturers written instructions

SCHEDULE

H	S	Post Size a x b	Connection "A" Type	Bolts	m	At "A" or "B" n	t x c x d	Connection "B" Type	Bolts	m	t x c x d	Basic Cost factor	Preservative	Painting	Staining
20#/φ horizontal loading															
5'	10'-0"	4x6	1	1-5/8 φ	–	–	PL 3/16 x 2 x 2	1	1-5/8 φ	–	PL 3/16 x 2 x 2	10.00	1.05	1.15	.86
10'	10'-0"	8x6	2	2-3/4 φ	9" o.c.	–	Bent PL 3/8 x 3	2	2-3/4 φ	9" o.c.	Bent PL 3/8 x 3	16.28	2.45	2.30	1.76
15'	10'-0"	12x6	3	4-3/4 φ	9" o.c.	7½" o.c.	Bent PL ½ x 10½	3A	4-3/4 φ	9" o.c.	Bent PL ½ x 10½	26.18	3.51	3.45	2.59
20'	10'-0"	Load too high for standard bolting										41.07	5.11	4.60	3.45
30#/φ horizontal loading															
5'	8'-0"	4x6	1	1-5/8 φ	—	—	PL ¼ x 2 x 2	1	1-5/8 φ	—	PL ¼ x 2 x 2	10.70	1.31	1.15	.86
10'	8'-0"	8x6	2	2-3/4 φ	9" o.c.	—	Bent PL 3/8 x 3	2	2-3/4 φ	9" o.c.	Bent PL 3/8 x 3	18.43	2.60	2.30	1.76
15'	8'-0"	14x6	3	4-3/4 φ	9" o.c.	7½" o.c.	Bent PL ½ x 10½	3A	4-3/4 φ	9" o.c.	Bent PL ½ x 10½	28.98	3.84	3.45	2.59
20'	6'-0"	Load too high for standard bolting										45.82	6.10	4.60	3.45
40#/φ horizontal loading															
5'	8'-0"	4x6	1	1-5/8 φ	—	—	PL ¼ x 2 x 2	1	1-5/8 φ	—	PL ¼ x 2 x 2	11.73	1.31	1.15	.86
10'	8'-0"	8x6	3	4-3/4 φ	9" o.c.	7½" o.c.	Bent PL 3/8 x 10½	2	2-3/4 φ	9" o.c.	Bent PL ½ x 10½	19.81	2.75	2.30	1.76
15'	6'-0"	14x6	3	4-3/4 φ	9" o.c.	7½" o.c.	Bent PL ½ x 10½	3A	4-3/4 φ	9" o.c.	Bent PL ½ x 10½	39.54	4.21	3.45	2.59
20'	6'-0"	Load too high for standard bolts										57.96	6.72	4.60	3.45

Bolt capacity chart - uninspected

Bolt Dia.	Embed	Shear cap#	Tension cap#
1/2"	4"	1000	950
5/8"	4"	1500	1500
3/4"	5"	1780	2250
7/8"	6"	2075	3200
1"	7"	2075	3200

Log bolt capacity chart uninspected

Bolt Dia.	Embed	Shear cap.#	Tension cap.#
1/2"	4"	300	300
5/8"	4"	360	340
3/4"	6"	630	400
7/8"	6"	730	450
1"	6"	800	490

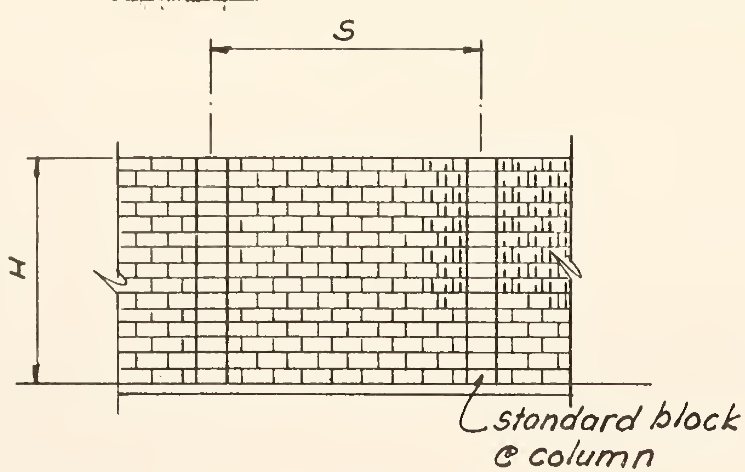
ACOUSTIC BARRIER
WOOD ON
ELEVATED STRUCTURE

EW-1

EW- 1 2 3

APPENDIX C

REFERENCE DRAWINGS FOR ABSORPTION TREATMENTS



ELEVATION

SCHEDULE

H	"SOUNDBLOX"	Paint One side
5'	5.58	1.27
10'	11.16	2.53
15'	16.73	3.80
20'	22.31	5.06
	a1	(1)

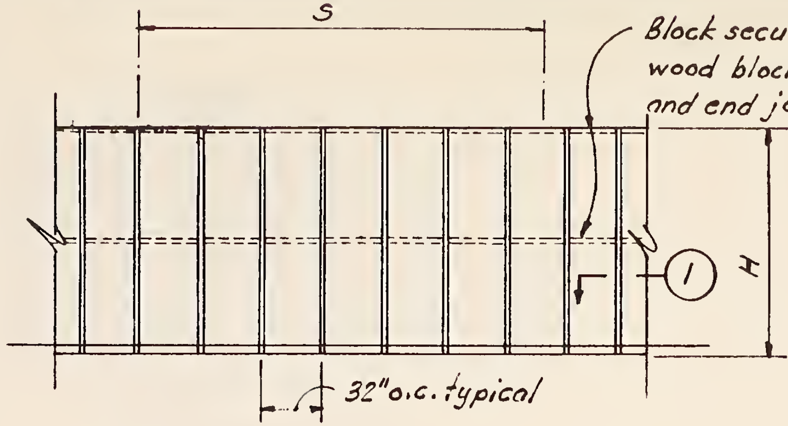
Notes:

1. All notes on sheets M-1 & M-2 apply to this drawing with the exception of "a" bars. "a" bars are to be replaced with 2-D7 wires @ 16" o.c. & 2-cross ties @ 48" o.c. (or 9 ga. ASW) placed in mortar joints.
2. Resonant cavity blocks are "SOUNDBLOX" as licensed by the Proudfoot Company Inc. or approved equal. 50% of the blocks are to be type "A" and 50% are to be type "B".
3. Cost factor for "SOUNDBLOX" is stated in the additional cost for this treatment which is added to the basic cost factor for the concrete block barrier, sheet M-1.

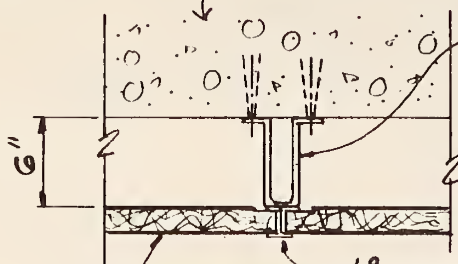
NRC = 0.55

A-1

ABSORPTION TREATMENT
CONCRETE MASONRY UNITS
RESONANT CAVITY BLOCKS



ELEVATION



SECTION 1

Notes:
1. All wood to be preservative treated.
2. Wood fiber planks to be manufactured with water resistant binder - such as Portland Cement
3. Painting to be two coats of non-bridging exterior latex paint.

SCHEDULE

H	Basic Cost Factor
5'	9.99
10'	19.91
15'	33.56
20'	45.79

a2

NRC = 0.50

A-2

ABSORPTION TREATMENT
WOOD FIBER PLANKS

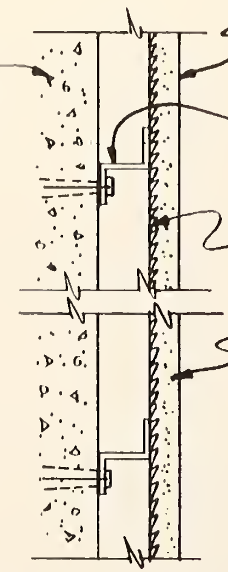
Notes:

1. Lightweight aggregate concrete is spray applied in accordance with manufacturers directions. One product is Pyrok, composed of 3 parts vermiculite, 1 part portland cement and 1/2 part lime.
2. Due to potential for cracking if saturated and frozen this system is not recommended for exposed conditions. Verify cleaning characteristics with manufacturer.
3. Provide vertical & horizontal expansion joints, maximum distance of 10 feet, with a maximum area of 100 square feet.

SCHEDULE

H	COST FACTOR
5'	11.20
10'	22.30
15'	37.84
20'	52.30

a3

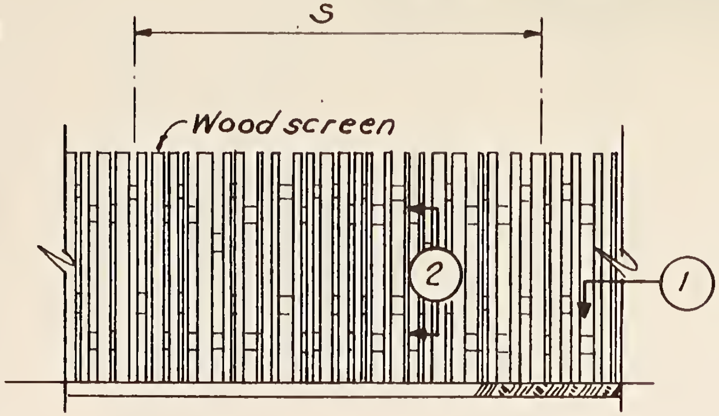


TYPICAL SECTION

NRC = .64

A-3

ABSORPTION TREATMENT
VERMICULITE
AGGREGATE CONCRETE

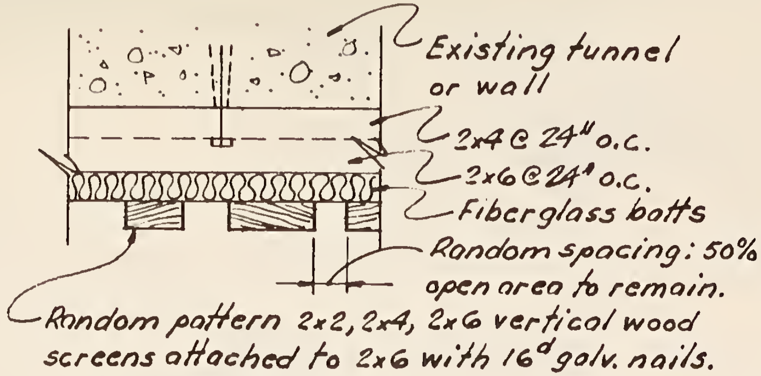


ELEVATION

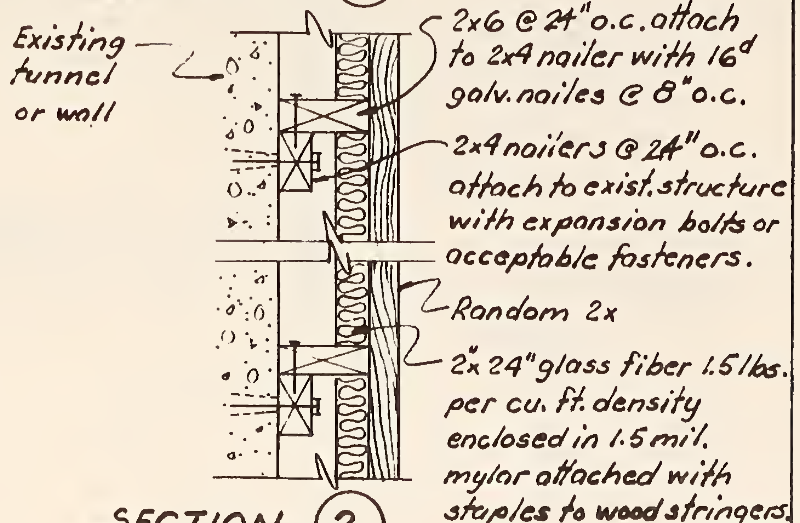
Notes:
1. All wood to be preservative treated.
2. Glass fiber batts to be enclosed in water tight covering of 1.5 mil mylar.
3. For curved tunnel surfaces wood screens may be applied horizontally.
4. The cost factor for the absorbtion treatment is stated on a lineal foot basis.

SCHEDULE

H	Basic Cost Factor	Painting
5'	6.16	1.04
10'	14.47	2.07
15'	21.80	3.11
20'	28.94	4.14



SECTION 1



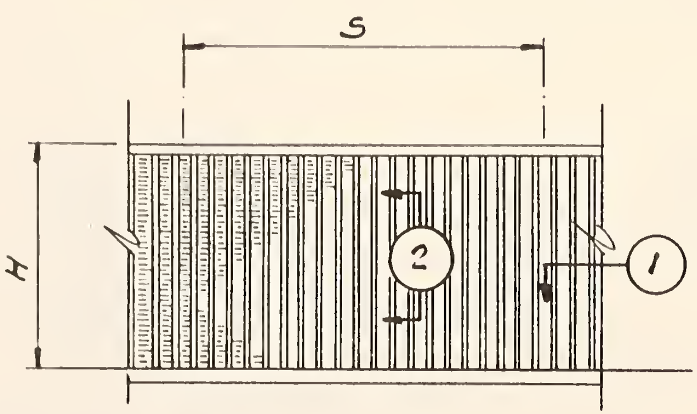
SECTION 2

NRC = 0.90

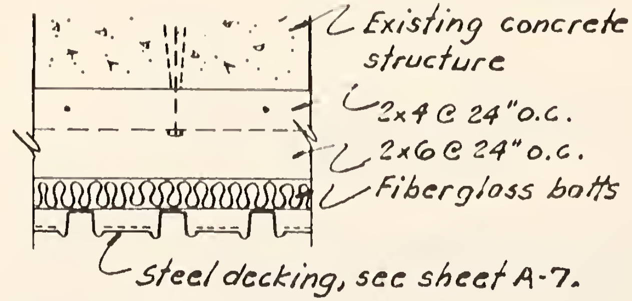
A-4

ABSORBTION TREATMENT GLASS FIBER BATTS WITH WOOD SCREEN

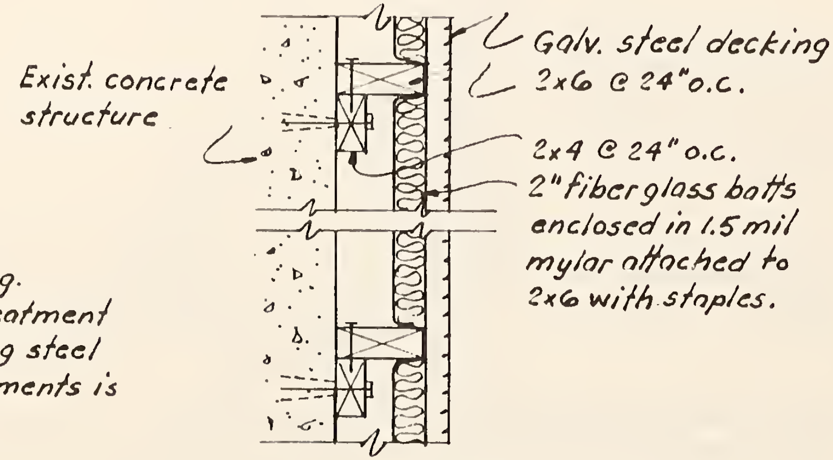
a4 (1)



ELEVATION



SECTION (1)



SECTION (2)

Notes:

1. All wood to be preservative treated.
2. Fiberglass batts to be enclosed in water tight covering of 1.6 mil mylar.
3. All notes on sheet S-1 apply to this drawing.
4. The cost factor indicated is for absorbtion treatment without special finish. If painting or weathering steel is to be selected the cost factor for these treatments is added to the basic cost factor.

SCHEDULE

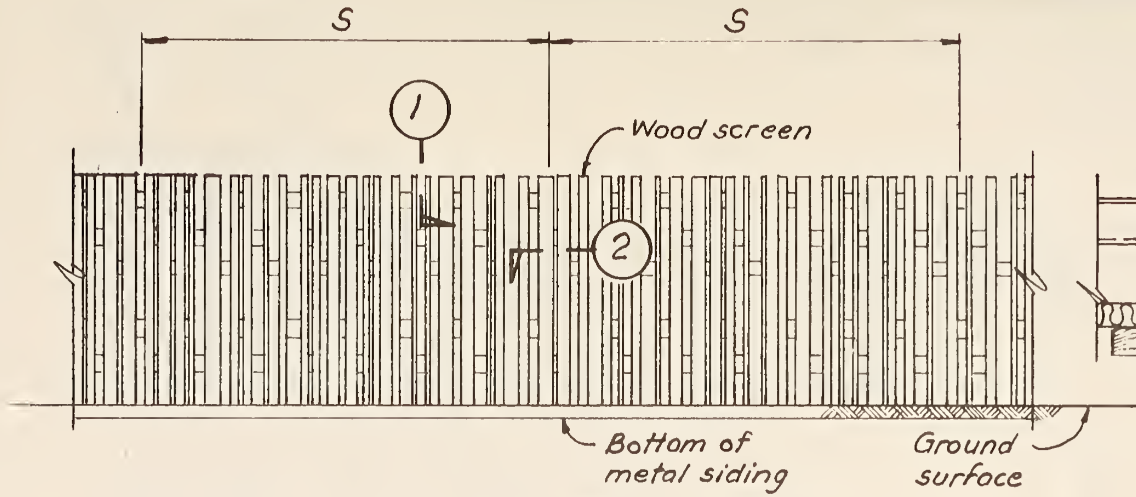
H	Basic Cost Factor	Painting	Weathering Steel
5'	12.94	.86	.58
10'	34.25	1.73	1.15
15'	48.64	2.59	1.73
20'	53.32	3.45	2.30

NRC = 0.90

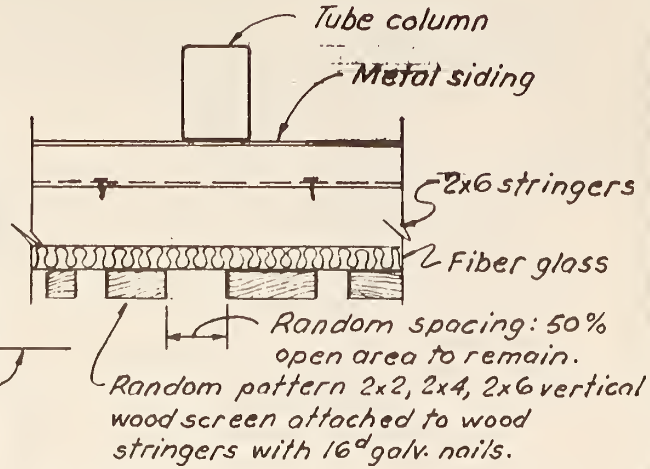
A-5

ABSORPTION TREATMENT
GLASS FIBER BATTS WITH
METAL SIDING

a5 (1) (2)



ELEVATION



SECTION 1

NOTES

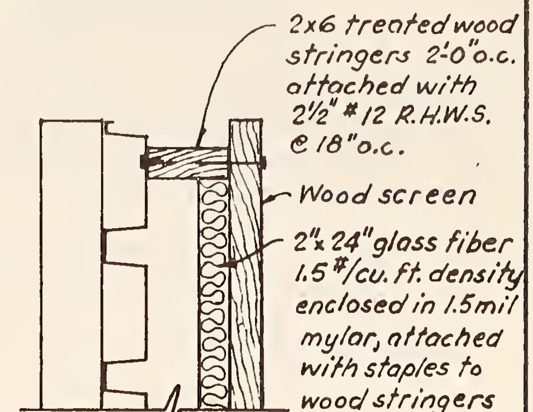
1. All notes, except notes no. 6 & 7 on sheet S-1 apply to this drawing
2. The cost factor for the acoustic barrier shown is stated on a lineal foot basis and is added to the basic structure to arrive at a total cost. See schedule below and sheet S-1.

SCHEDULE

H	Cost factor
5'	5.29
10'	10.58
15'	15.87
20'	21.16

a6

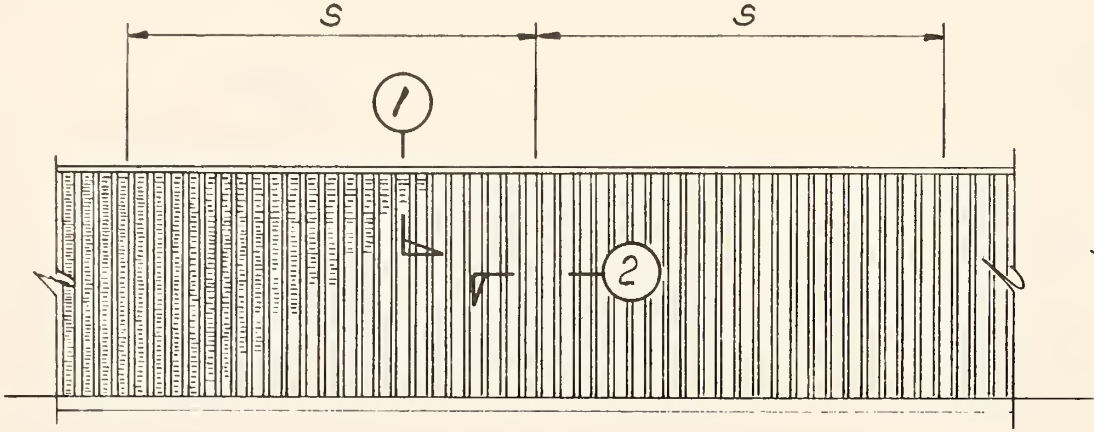
NRC = 0.90



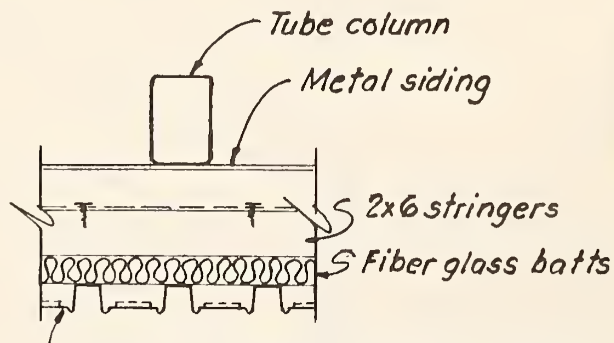
SECTION 2

A-6

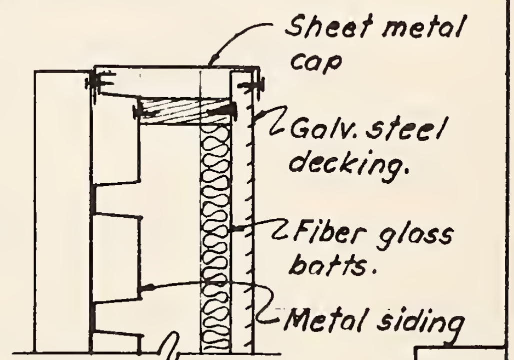
ABSORPTION TREATMENT
GLASS FIBER W/ WOOD SCREEN
ON STEEL BARRIER



ELEVATION



SECTION 1



SECTION 2

NOTES

1. All notes on sheet S-1 apply to to this drawing.
2. Sheet metal cap to be 20 ga. sheet metal attached with self-drilling screws, #10-16x3/4" spaced at 18" o.c.
3. 2x6 treated wood stringers spaced at 6'-0" o.c. max. attached with 2½" long #12 RHWS @ 18" o.c.
4. Fiber glass batts to be 2"x 24" normal glass fiber batts, 1.5 lbs. per cu. ft. enclosed in 1.5 mil mylar with tabs, staple to wood stringers.
5. The cost factor for the acoustic barrier shown is stated on a lineal foot basis and is added to the basic structure to arrive at a total cost, see sheet S-1. See schedule below

SCHEDULE

H	Cost factor
5'	6.33
10'	12.77
15'	19.15
20'	25.53

NRC = 0.90

A-7

ABSORPTION TREATMENT
GLASS FIBER W/METAL SIDING
ON STEEL BARRIER

a7

APPENDIX D

DESIGN EXAMPLES FOR EXISTING NOISE BARRIERS

APPENDIX D
DESIGN EXAMPLES FOR EXISTING NOISE BARRIERS

The examples presented herein are intended to illustrate the type of results attainable through use of the barrier design procedure contained in Chapter 4. The highway sites chosen for the examples are sites at which actual noise barriers have been constructed by various state highway departments. In all cases, field-measured barrier attenuation data have been selected as noise reduction requirements for use in the design procedure. Design options are developed based on construction drawings and reports relating to the existing barrier sites. Finally, costs for each option are defined, referenced back to the date of actual barrier construction. Thus, the results of each example consist of a set of possible design options which are expected to provide the same noise reduction as the existing barrier, as well as comparative construction costs for these options.

EXAMPLE 1: MINNEAPOLIS, MINNESOTA (PROSPECT PARK)
I-94 (WESTBOUND)

The existing noise barrier at this site consists of a pre-cast concrete panel wall, 3568 ft. long and 10-23 ft. high. It was constructed in the summer of 1974 at a cost of $4.53 per sq. ft.

For the purposes of this example, an 800 ft. highway element is considered, from station 185 to 193. The object is to obtain alternative designs for this section, assuming it to be part of a continuous barrier. Thus, a subtended angle (θ) of 180° is assumed in the calculations. Due to the limited distance between the edge of the traveled way and Frontage Rd., only one barrier location option is considered. A design attenuation goal of 12 dBA is assumed for an observer location at a nearby residence. On this basis, a height of 14 ft. is calculated, using the barrier nomograph procedure. A profile drawing of the barrier site, indicating source, observer and barrier locations, is given in Figure 1-1.

Selected design options for the chosen barrier location are presented in Table 1-1. The table lists the barrier design codes and descriptions as well as the various constraints and additional treatment options. Note that construction of an earth berm has been ruled out, due to the limited right-of-way available.

The definition of cost factors for the various barrier design options is illustrated in Table 1-2. Total estimated costs for each option are also presented, referenced to the date and location of construction. A city index of 97 and an inflation index (to 1975) of 111.2 are assumed in the calculations.

The approximate actual cost of the 800 ft. section was $76,000, based on a height of 21 ft. for this section at $4.53 per sq. ft. Note that the predicted costs for concrete, masonry and wood barrier designs range between $56,000 and $78,000. Predicted costs for steel barrier designs are significantly higher, in excess of $100,000.

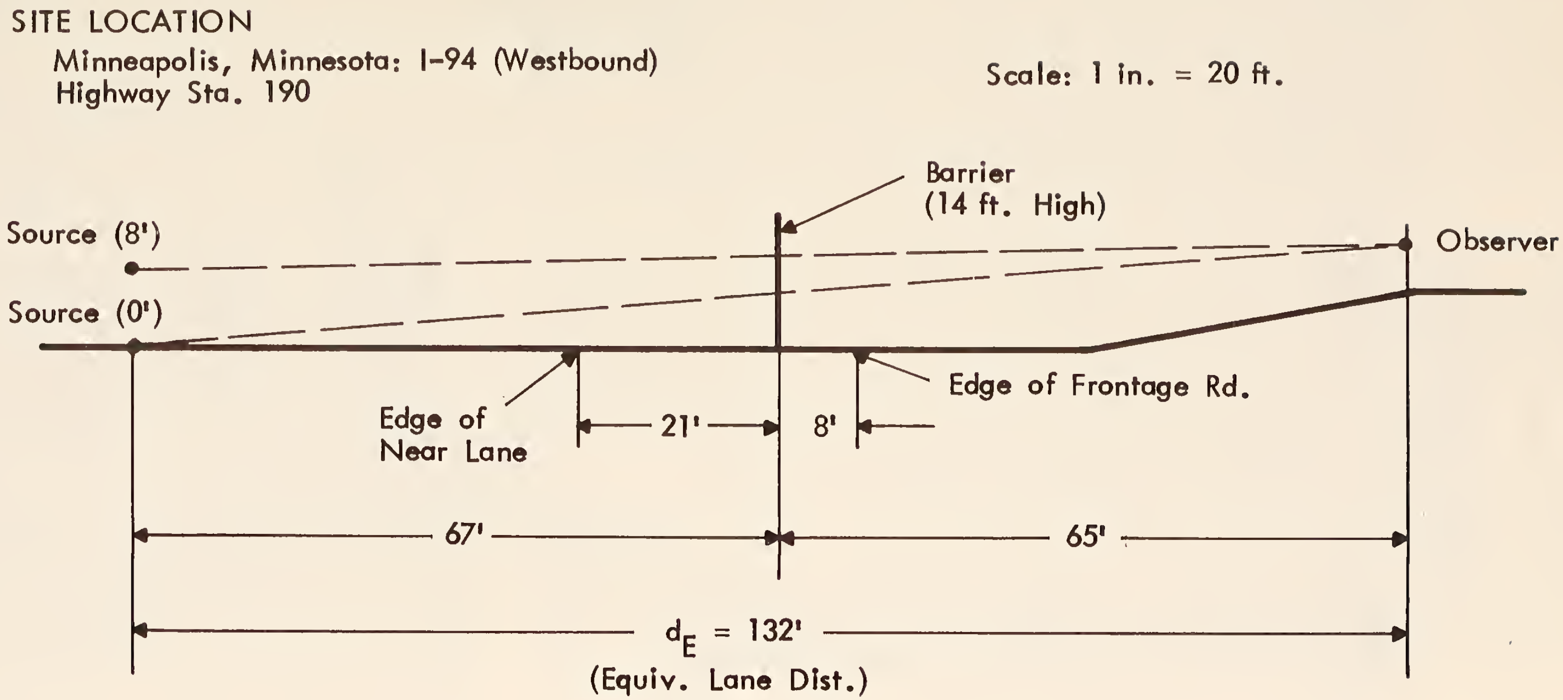


FIGURE 1-1. EXAMPLE 1 - BARRIER SITE PROFILE

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 21/ 14 / 800	No. 2 / /	No. 3 / /
Pre-Cast Concrete	C-8-S		
	C-8,2-S		
	C-8,6-S		
Concrete Masonry Block	M-6-S		
	M-6,4-S		
	M-6,5-S		
Steel	S-5-S		
	S-5,1-S		
	S-5,3-S		
Wood	W-3-S		
	W-5,5-S		
	W-4,4-S		

Wind Loading	40 lb/ft^2	Safety Barrier	YES
Aesthetics	YES	Absorption	NO
Weathering	YES	Other Comments	

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
C-8	Concrete w/integral color	NO
C-8,2	Concrete w/integral color + sandblast	NO
C-8,6	Concrete w/integral color + rubber mat inserts	NO
M-6	Masonry w/integral color	NO
M-6,4	Masonry w/integral color + combed units	NO
M-6,5	Masonry w/integral color + split face	NO
S-5	Steel w/weathering	NO
S-5,1	Steel w/weathering + sheet metal trim	NO
S-5,3	Steel w/weathering + sheet metal trim & stucco	NO
W-3	Wood w/preservative	NO

TABLE 1-1. EXAMPLE 1 - BARRIER DESIGN OPTIONS

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 21 / 14 / 800	No. 2 / /	No. 3 / /

Wind Loading ______________ Safety Barrier ______________

Aesthetics ______________ Absorption ______________

Weathering ______________ Other Comments ______________

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
W-5,5	Wood w/stain (both sides)	NO
W-4,4	Wood w/painting (both sides)	NO

TABLE 1-1. EXAMPLE 1 - BARRIER DESIGN OPTIONS (cont'd)

COST FACTOR WORKSHEET

Wind Loading 40 lbs. per sq. ft.

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS					TOTAL COST
				Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	
C-8-S	1	14	800	79.10	0.33	12.08	--	91.51	63,700
C-8,2-S	1	14	800	79.10	3.23	12.08	--	94.41	65,700
C-8,6-S	1	14	800	79.10	12.24	12.08	--	103.42	72,000
M-6-S	1	14	800	61.78	6.60	12.08	--	80.46	56,000
M-6,4-S	1	14	800	61.78	13.84	12.08	--	87.70	61,000
M-6,5-S	1	14	800	61.78	38.80	12.08	--	112.66	78,400
S-5-S	1	14	800	132.99	3.55	12.08	--	148.62	103,400
S-5,1-S	1	14	800	132.99	9.99	12.08	--	155.06	107,900
S-5,3-S	1	14	800	132.99	26.09	12.08	--	171.16	119,100
W-3-S	1	14	800	66.91	3.92	12.08	--	82.91	57,700
W-5,5-S	1	14	800	66.91	4.85	12.08	--	83.84	58,400
W-4,4-S	1	14	800	66.91	6.44	12.08	--	85.43	59,500

TABLE 1-2. EXAMPLE 1 - COST FACTOR DETERMINATION

EXAMPLE 2: MINNEAPOLIS, MINNESOTA (MINNEHAHA CREEK) I-35W

The existing noise barrier at this site consists of parallel, non-absorptive wooden walls on landscaped earth mounds. The walls are pressure treated and are faced with vertical battens. The barrier was constructed in the fall of 1972 at a cost of $100 per ft.

For the purposes of this example, only the northbound side of the highway is considered, except that the reflection effects from a parallel barrier are taken into account. A design attenuation goal of 6 dBA is assumed for an observer location on a residential street (E. 53rd St.). In addition, a barrier length of 1900 ft. (station 97-116) is assumed to be required to protect other observer locations along the highway. Using the barrier design procedure, three geometrical options are identified as follows:

1. P_R = 16 ft.	2. P_R = 56 ft.	3. P_R = 96 ft.
H = 8 ft.	H = 12 ft.	H = 17 ft.
L = 1900 ft.	L = 1900 ft.	L = 1900 ft.

where: P_R = position of barrier (distance to roadway)
H = barrier height
L = barrier length

A profile drawing of the barrier site, indicating the source, observer and barrier locations, is given in Figure 2-1.

Since a parallel barrier is to be constructed, the need for applying acoustically absorptive material on the highway side of the barrier needs to be considered. The nomograph method of the barrier design procedure estimates a degradation (ΔBAR) of 4 dBA for 8 ft. sources (trucks) and 6 dBA for zero ft. sources (autos), assuming the closest-in barrier location. Application of absorptive linings is expected to reduce the degradations to 1 dBA and 3 dBA, respectively. Thus, the total degradation is reduced from approximately 5 dBA to 2 dBA. Therefore, absorptive linings are considered in the barrier design.

Selected design options for the chosen barrier locations are presented in Table 2-1. The table lists the barrier design codes and descriptions as well as the various constraints and additional treatment options. Note that a combination earth berm and wooden wall is considered for location 2 only, due to space restrictions. Note also that a safety barrier is required for location 1 only, since this location is less than 30 feet from the highway.

The definition of cost factors for the various barrier design options is illustrated in Table 2-2. Total estimated costs for each option are also presented, referenced to the date and location of construction. A city index of 97 and an inflation index (to 1975) of 130.0 are assumed in the calculations.

The approximate actual cost of the 1880 ft. wall was $188,000. The predicted costs are seen to rise sharply with increasing barrier distance from the highway. Choosing a close-in position takes advantage of the pre-barrier ground profile. Finally, note that the concrete and steel designs are significantly more expensive than the other material options.

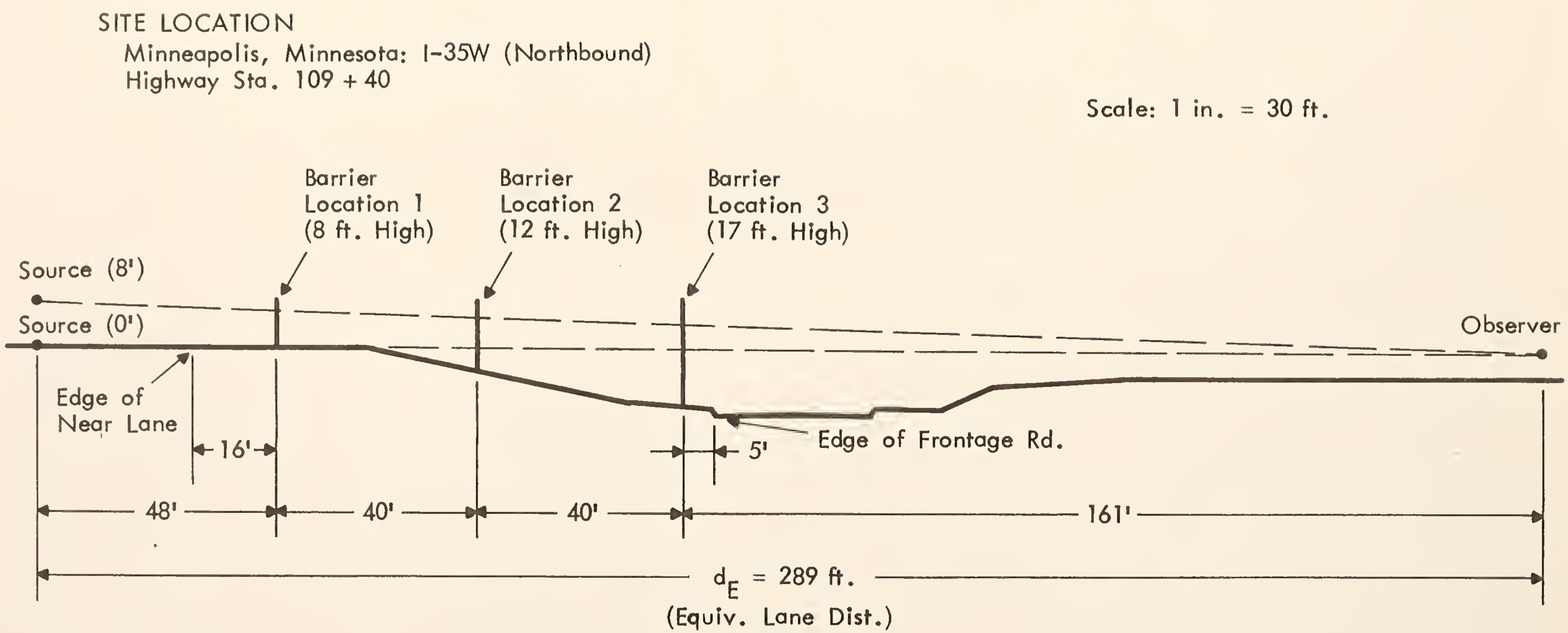


FIGURE 2-1. EXAMPLE 2 - BARRIER SITE PROFILE

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 16 / 8 / 1900	No. 2 56 / 12 / 1900	No. 3 96 / 17 / 1900
Pre-Cast	C-8-S-a5(2)	C-8-a5(2)	C-8-a5(2)
Concrete	C-8,5-S-a5(2)	C-8,5-a5(2)	C-8,5-a5(2)
Concrete	M-S-a1	M-a1	M-a1
Masonry	M-S-a1(1)	M-a1(1)	M-a1(1)
Block			
Steel	S-5-S-a6	S-5-a6	S-5-a6
	S-5-a7	S-5-a7	S-5-a7
Wood	W-3-S-a4	W-3-a4	W-3-a4
	W-3,2-S-a4	W-3,2-a4	W-3,2-a4

Wind Loading	40 lb/ft^2	Safety Barrier	Position 1 only
Aesthetics	YES	Absorption	YES
Weathering	YES	Other Comments	

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
C-8-a5(2)	Concrete w/integral color + glass fiber/	
	weathering metal siding abs. treatment	YES (by 2 dB)
C-8,5-a5(2)	Concrete w/integral color + reinforcing bar	
	inserts + glass fiber/weathering metal siding	
	abs treatment	YES (by 2 dB)
M-a1	Masonry w/resonant cavity blocks	YES (by 2 dB)
M-a1(1)	Masonry w/resonant cavity blocks + painting	YES (by 2 dB)
S-5-a6	Steel w/weathering steel + glass fiber/wood	
	abs. treatment	YES (by 2 dB)

TABLE 2-1. EXAMPLE 2 - BARRIER DESIGN OPTIONS

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 16 / 8 / 1900	No. 2 56 / 12 / 1900	No. 3 96 / 17 / 1900
Earth Berm & Wooden Wall		B(3)-1;W-3,2-a4	

Wind Loading __________ Safety Barrier __________

Aesthetics __________ Absorption __________

Weathering __________ Other Comments __________

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
S-5-a7	Steel w/weathering steel + glass fiber/metal	
	abs. treatment	YES (by 2 dB)
W-3-S-a4	Wood w/preservative + glass fiber/wood facing	
	abs. treatment	YES (by 2 dB)
W-3,2-S-a4	Wood w/preservative + vertical battens + glass	
	fiber/wood facing abs. treatment	YES (by 2 dB)
B(3)-1	Berm w/3:1 slope + landscaping (combine with	YES (by 2 dB)
	above wall, each 6 feet high)	

TABLE 2-1. EXAMPLE 2 - BARRIER DESIGN OPTIONS (cont'd)

COST FACTOR WORKSHEET

Wind Loading 40 lbs. per sq. ft.

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS					TOTAL COST
				Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	
C-8-S-									
a5(2)	1	8	1900	41.59	0.19	12.08	26.65	80.51	114,700
C-8-a5(2)	2	12	1900	65,49	0.28	--	41.35	107.12	152,600
C-8-a5(2)	3	17	1900	98.47	0.39	--	52.41	151.27	215,600
C-8,5-									
a5(2)	1	8	1900	41.59	5.90	12.08	26,65	86.22	122,900
C-8,5-									
a5(2)	2	12	1900	65.49	8.84	--	41.35	115.68	164,800
C-8,5-									
a5(2)	3	17	1900	98.47	12.51	--	52.41	163.39	232,800
M-S-a1	1	8	1900	30.47	--	12.08	8.93	51.48	73,400
M-a1	2	12	1900	50.09	--	--	13.39	63.48	90,500
M-a1(1)	3	17	1900	71.30	--	--	18.96	90.26	128,600
M-S-a1(1)	1	8	1900	30.47	2.03	12.08	8.93	53.51	76,300
M-a1(1)	2	12	1900	50.09	3.04	--	13.39	66.52	94,800
M-a1(1)	3	17	1900	71.30	4.30	--	18.96	94.56	134,700
S-5-S-a6	1	8	1900	60.72	2.03	12.08	8.46	83.29	118,700
S-5-a6	2	12	1900	105.71	3.04	--	12.70	121.45	173,100
S-5-a6	3	17	1900	189.18	4.30	--	17.99	211.47	301,300
S-S-a7	1	8	1900	60.72	2.03	12.08	10.19	85.02	121,200
S-5-a7	2	12	1900	105.71	3.04	--	15.32	124.07	176,800
S-5-a7	3	17	1900	189.18	4.30	--	21.70	215.18	306,600
W-3-S-a4	1	8	1900	30.39	2.17	12.08	11.15	55.79	79,500
W-3-a4	2	12	1900	53.06	3.33	--	17.40	73.79	105,200
W-3-a4	3	17	1900	94.81	5.21	--	24.66	124.68	177,700
W-3,2-S-									
a4	1	8	1900	30.39	3.20	12.08	11.15	56.82	81,000
W-3,2-a4	2	12	1900	53.06	5.14	--	17.40	75.60	107,700

TABLE 2-2. EXAMPLE 2 - COST FACTOR DETERMINATION

COST FACTOR WORKSHEET

Wind Loading

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS					TOTAL COST
				Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	
W-3,2-a4	3	17	1900	94.81	8.14	--	24.66	127.61	181,800
B(3)-1	2	6	1900						
W-3,2-a4	2	6	1900	28.60	29.63	--	7.82	66.05	94,100

TABLE 2-2. EXAMPLE 2 - COST FACTOR DETERMINATION (cont'd)

EXAMPLE 3: WEST HARTFORD, CONNECTICUT I-84 (EASTBOUND)

The existing noise barrier at this site consists of a landscaped earth berm, 1800 ft. long and approximately 14 ft. high. It was constructed in June, 1974 at a total cost of $150,000.

For the purposes of this example, two observer locations are considered as follows:

A. At curb, near 45 Wilfred St., along highway station 363
B. At curb, near 123 Wilfred St., along highway station 353

The design attenuation goals are 10 dBA for location A and 4 dBA for location B. Using the barrier design procedure, based on the more critical observer location A, three geometrical options are identified as follows:

1.	2.	3.
P_R = 15 ft.(A&B)	P_R = 60 ft.(A) = 40 ft.(B)	P_R = 100 ft.(A) = 65 ft.(B)
H = 23 ft.	H = 14 ft.	H = 11.5 ft.
L = 1400 ft.	L = 1400 ft.	L = 1400 ft.

where: P_R = position of barrier (distance to roadway)
H = barrier height
L = barrier length

Note that the barrier positions vary with respect to the highway, due to variations in the right-of-way width along the length of the barrier. Profile drawings of the barrier site, indicating source, observer and barrier locations, are given in Figure 3-1. Figure 3-2 presents plan views of the barrier options. Although the options are initially developed based on the attenuation goal at observer location A, repeated checks of the resultant predicted attenuations for location B ensure that the selected options also satisfy the goal at the latter observer location.

Selected design options for the chosen barrier locations are presented in Table 3-1. The table lists the barrier design codes and descriptions as well as the various constraints and additional treatment options. Note that an earth berm is considered for location 2 only, due to space requirements. In addition, safety barriers are required for all options at location 1, due to the close proximity to the highway.

The definition of cost factors for the various barrier design options is illustrated in Table 3-2. Total estimated costs for each option are also presented, referenced to the date and location of construction. A city index of 97 and an inflation index (to 1975) of 112.0 are assumed in the calculations.

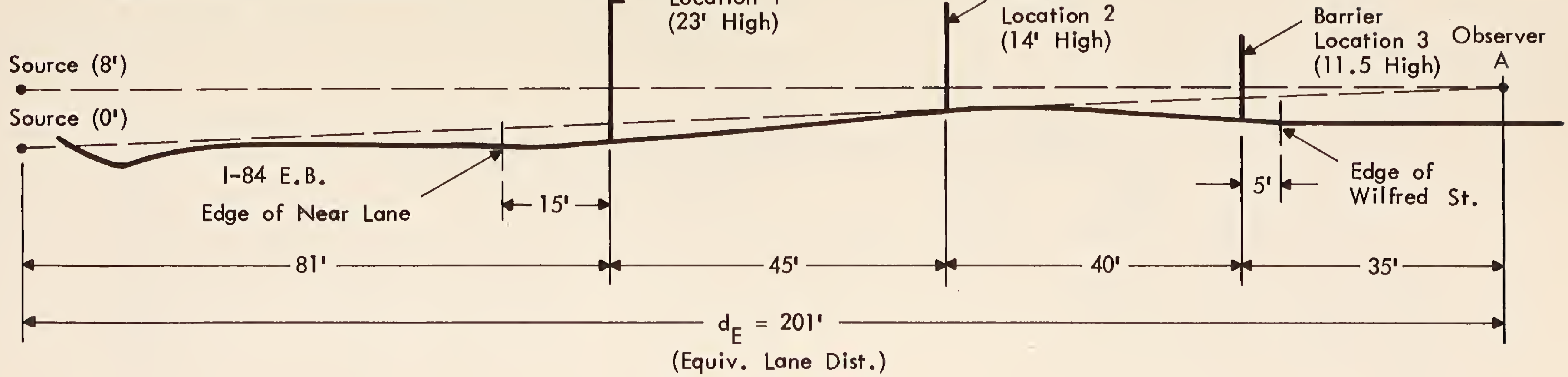
The predicted barrier costs are seen to drop sharply with increasing barrier distance from the highway due to the pre-barrier ground profile. The barrier materials, listed in order of increasing costs, are masonry, wood, concrete, earth berm and steel.

SITE LOCATION

West Hartford, Connecticut: I-84 (Eastbound)

Scale: 1 in. = 20 ft.

A. Highway Sta. 363 (45 Wilfred St.)



B. Highway Sta. 353 (123 Wilfred St.)

Scale: 1 in. = 20 ft.

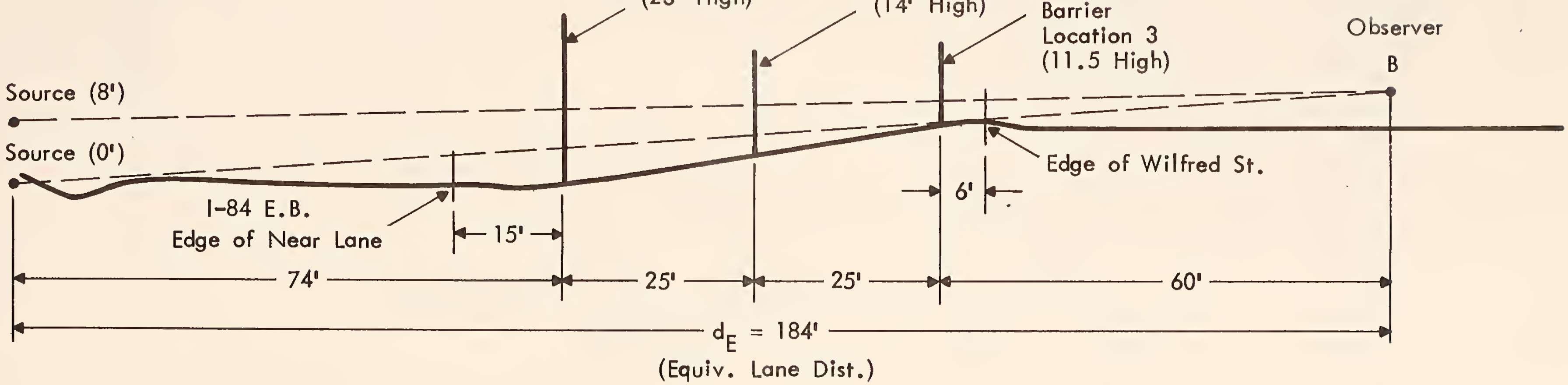


FIGURE 3-1. EXAMPLE 3 - BARRIER SITE PROFILES

SITE LOCATION - West Hartford, Connecticut: I-84 (Eastbound)

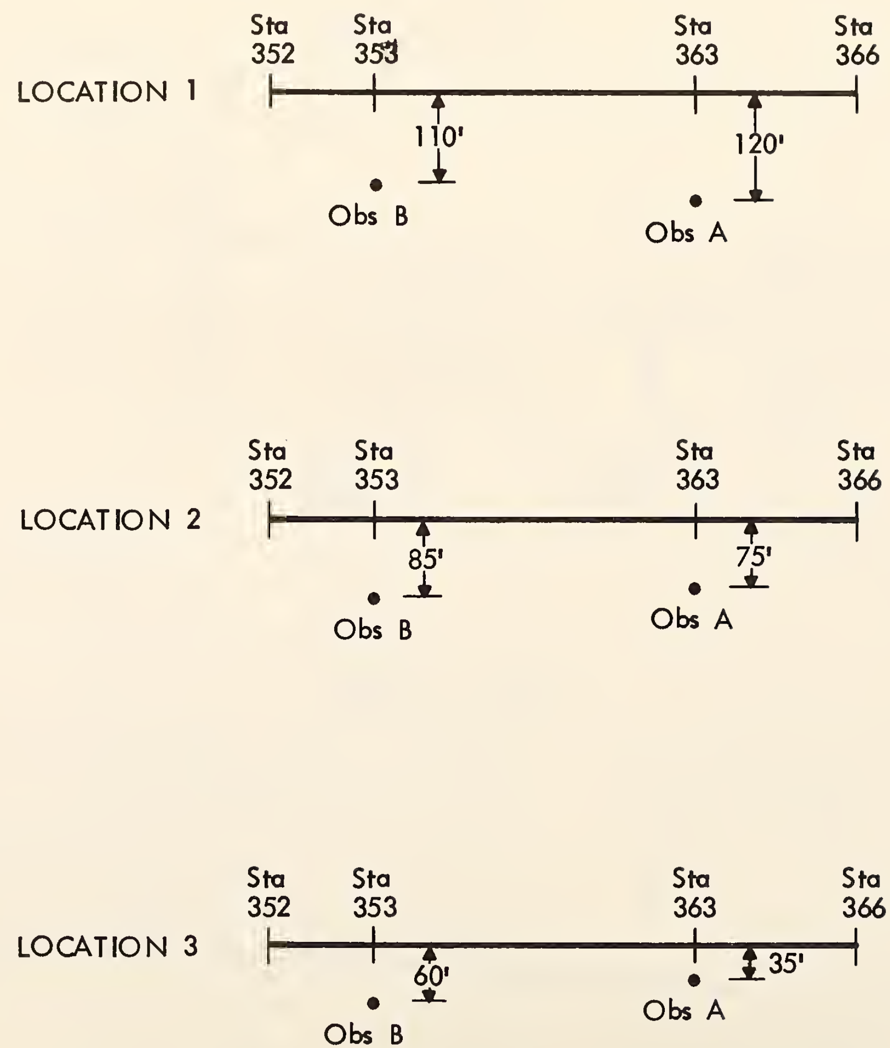


FIGURE 3-2. EXAMPLE 3 - BARRIER SITE PLANS

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 15 / 23 / 1400	No. 2 40-60 / 14 / 1400	No. 3 65-100/11.5 / 1400
Pre-Cast Concrete	C-8,S	C-8	C-8
	C-8,1-S	C-8,1	C-8,1
Concrete Masonry Block	M-6-S	M-6	M-6
	M-6,1-S	M-6,1	M-6,1
Steel	S-5-S	S-5	S-5
	S-5,2-S	S-5,2	S-5,2
Wood	W-3-S	W-3	W-3
	W-3,1-S	W-3,1	W-3,1

Wind Loading	30 lb/ft^2	Safety Barrier	Position 1 only
Aesthetics	YES	Absorption	NO
Weathering	YES	Other Comments	

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
C-8	Concrete w/integral color	NO
C-8,1	Concrete w/integral color + exposed aggregate	NO
M-6	Masonry w/integral color	NO
M-6,1	Masonry w/integral color + vertical scored block	NO
S-5	Steel w/weathering steel	NO
S-5,2-5	Steel w/weathering steel + sheet metal trim &	
	wood veneer	NO
W-3	Wood w/preservative	No
W-3,1	Wood w/preservative + plywood facing	NO
B(2)-1	Earth berm w/2:1 slope + landscaping	NO

TABLE 3-1. EXAMPLE 3 - BARRIER DESIGN OPTIONS

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 15 / 23 / 1400	No. 2 40-60 / 14 / 1400	No. 3 65-100/ 11.5/ 1400
Earth Berm		B(2)-1	

Wind Loading __________ Safety Barrier __________

Aesthetics __________ Absorption __________

Weathering __________ Other Comments __________

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?

TABLE 3-1. EXAMPLE 3 - BARRIER DESIGN OPTIONS (cont'd)

COST FACTOR WORKSHEET

Wind Loading 30 lbs. per sq. ft.

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS					TOTAL COST
				Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	
C-8-S	1	23	1400	132.21	0.53	12.08	--	144.82	176,400
C-8	2	14	1400	80.71	0.33	--	--	81.04	98,700
C-8	3	11.5	1400	62.11	0.27	--	--	62.38	76,000
C-8,1-S	1	23	1400	132.21	6.61	12.08	--	150.90	183,800
C-8,1	2	14	1400	80.71	4.04	--	--	84.75	103,200
C-8,1	3	11.5	1400	62.11	3.32	--	--	65,43	79,700
M-6-S	1	23	1400	77.49	10.85	12.08	--	100.42	122,312
M-6	2	14	1400	55.40	6.60	--	--	62.00	75,500
M-6	3	11.5	1400	42.98	5.43	--	--	48.41	59,000
M-6,1-S	1	23	1400	77.49	22.75	12.08	--	112.32	136,800
M-6,1	2	14	1400	55.40	13.84	--	--	69.24	84,300
M-6,1	3	11.5	1400	42.98	11.38	--	--	54.36	66,200
S-5-S	1	23	1400	279.33	5.82	12.08	--	297.23	362,000
S-5	2	14	1400	118.96	3.55	--	--	122.51	149,200
S-5	3	11.5	1400	92.91	2.91	--	--	95.82	116,700
S-5,2-S	1	23	1400	279.33	30.68	12.08	--	322.09	392,300
S-5,2	2	14	1400	118.96	18.69	--	--	137.65	167,700
S-5,2	3	11.5	1400	92.91	15.34	--	--	108.25	131,800
W-3-S	1	23	1400	139.67	7.46	12.08	--	159.21	193,900
W-3	2	14	1400	59.48	3.59	--	--	63.07	76,800
W-3	3	11.5	1400	46.46	2.97	--	--	49.43	60,200
W-3,1-S	1	23	1400	139.67	20.95	12.08	--	172.70	210,300
W-3,1	2	14	1400	59.48	11.80	--	--	71.28	86,800
W-3,1	3	11.5	1400	46.46	9.72	--	--	56.18	68,400
B(2)-1	2	14	1400	21.76	41.63	--	--	63.39	73,200

TABLE 3-2. EXAMPLE 3 - COST FACTOR DETERMINATION

EXAMPLE 4: SAN GABRIEL, CALIFORNIA
I-10 (WESTBOUND)

The existing noise barrier at this site consists of a concrete block wall, 1925 ft. long and 13 ft. high. The wall has an architectural facing of brick and stucco, with a top of red tiles, and is curved at both ends. It was constructed in December, 1973 at a total cost of $145,000.

For the purposes of this example it is assumed that barrier construction is limited to the highway element between stations 457 and 475. A design attenuation goal of 14 dBA is assumed for an observer location 100 ft. from the near edge of the westbound lane, at highway station 471. Utilizing the barrier design procedure, it is determined that for a maximum length, straight barrier (1800 ft. long) a barrier height of 33 ft. is required. Since this height is deemed impractical, consider curving back the two ends of the barrier in order to provide an increased effective length by increasing the subtended angle (θ). This approach results in an allowable barrier height of 16 ft. with an overall length of 2000 linear ft. as shown in the profile drawing of Figure 4-1 and the plan view of Figure 4-2. Note that due to limited distance between the right-of-way limit and an on-ramp traffic lane, only one barrier location is considered in this example.

Selected design options for the chosen barrier location are presented in Table 4-1. The table lists the barrier design codes and descriptions as well as the various constraints and additional treatment options. Note that construction of an earth berm is not practical in this case due to the limited right-of-way and that a safety barrier is required due to the close proximity to the on-ramp traffic lane.

The definition of cost factors for the various barrier design options is illustrated in Table 4-2. Total estimated costs for each option are also presented, referenced to the date and location of construction. A city index of 96 and an inflation index of 118.8 are assumed in the calculations.

Note that the actual cost of the barrier is comparable to predicted costs for wood and masonry walls and is $25,000 to $45,000 less than the predicted costs for concrete barriers. The predicted costs for the steel barrier options are significantly greater than costs for the other material types.

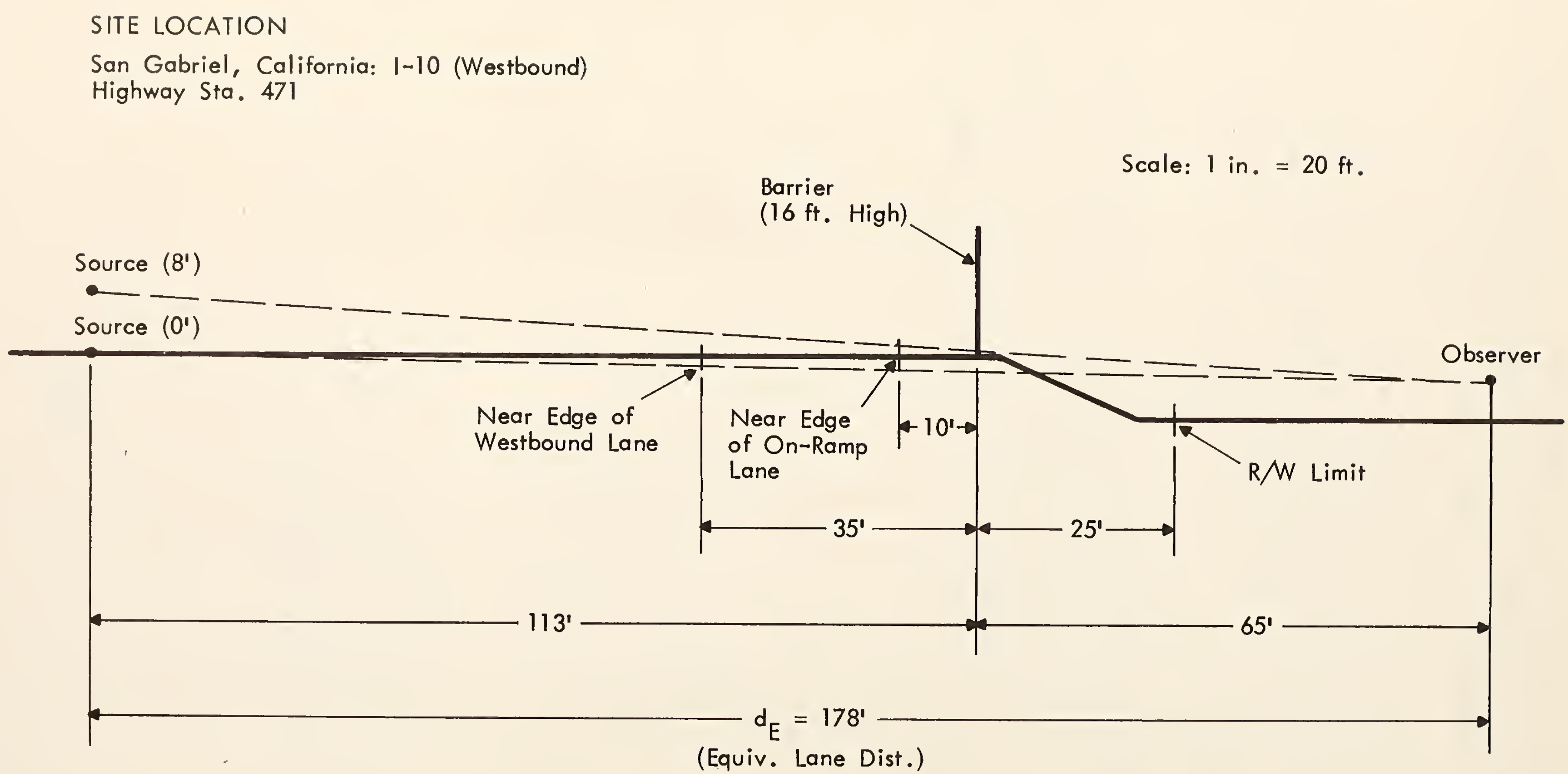


FIGURE 4-1. EXAMPLE 4 - BARRIER SITE PROFILE

SITE LOCATION

San Gabriel, California: I-10 (Westbound)

Scale: 1 in. = 200 ft.

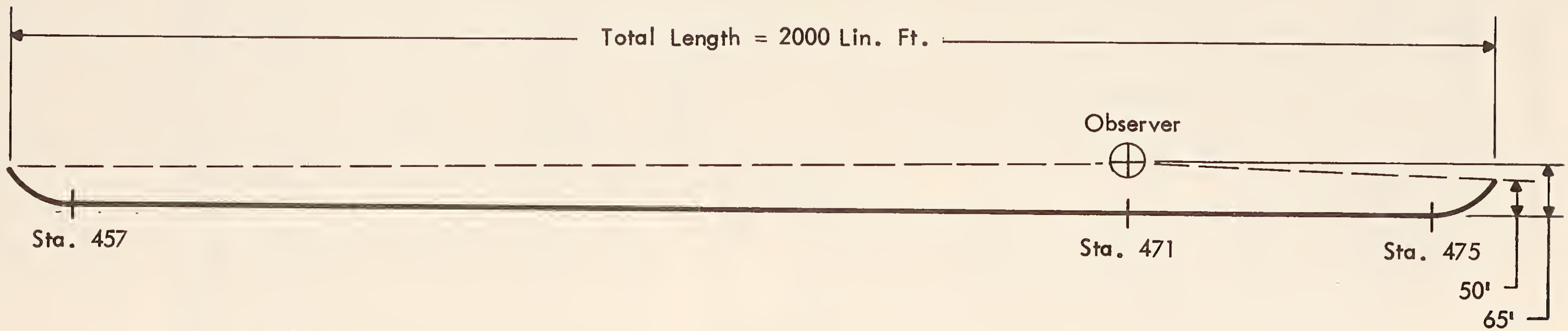


FIGURE 4-2. EXAMPLE 4 - BARRIER SITE PLAN VIEW

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 10 / 16 /2000	No. 2 / /	No. 3 / /
Pre-Cast Concrete	C-S		
	C-9,9-S		
	C-4-S		
Concrete Masonry Block	M-S		
	M-7,7-S		
	M-3-S		
Steel	S-5-S		
	S-4,4-S		
	S-5,3-S		
Wood	W-3-S		
	W-4,4-S		
	W-3,2-S		

Wind Loading $30\ lb/ft^2$ Safety Barrier YES

Aesthetics YES Absorption NO

Weathering YES Other Comments

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
C	Concrete untreated	NO
C-9,9	Concrete w/painting (both sides)	NO
C-4	Concrete w/wood form inserts	NO
M	Masonry untreated	NO
M-7,7	Masonry w/painting (both sides)	NO
M-3	Masonry w/4" slump block	NO
S-5	Steel w/weathering	NO
S-4,4	Steel w/painting (both sides)	NO
S-5,3	Steel w/weathering + sheet metal trim & stucco	NO

TABLE 4-1. EXAMPLE 4 - BARRIER DESIGN OPTIONS

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 10 / 16 / 2000	No. 2 / /	No. 3 / /

Wind Loading ______________ Safety Barrier ______________

Aesthetics ______________ Absorption ______________

Weathering ______________ Other Comments ______________

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
W-3	Wood w/preservative	NO
W-4,4	Wood w/painting (both sides)	
W-3,2	Wood w/preservative + vertical battens	NO

TABLE 4-1. EXAMPLE 4 - BARRIER DESIGN OPTIONS (cont'd)

COST FACTOR WORKSHEET

Wind Loading 30 lbs. per sq. ft.

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS					TOTAL COST
				Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	
C-S	1	16	2000	93.66	--	12.08	--	105.74	171,300
C-9,9-S	1	16	2000	93.66	7.14	12.08	--	112.88	182,900
C-4-S	1	16	2000	93.66	11.96	12.08	--	117.70	190,700
M-S	1	16	2000	62.51	--	12.08	--	74.59	120,800
M-7,7-S	1	16	2000	62.51	8.10	12.08	--	82.69	134,000
M-3-S	1	16	2000	62.51	36.80	12.08	--	111.39	180,500
S-5-S	1	16	2000	148.12	4.05	12.08	--	164.25	266,100
S-4,4-S	1	16	2000	148.12	5.52	12.08	--	165.72	268,500
S-5,3-S	1	16	2000	148.12	29.81	12.08	--	190.01	307,800
W-3-S	1	16	2000	74.06	4.29	12.08	--	90.43	146,500
W-4,4-S	1	16	2000	74.06	7.35	12.08	--	93.50	151,500
W-3,2-S	1	16	2000	74.06	7.05	12.08	--	93.19	151,000

TABLE 4-2. EXAMPLE 4 - COST FACTOR DETERMINATION

EXAMPLE 5: ALLEN PARK, MICHIGAN
I-75 (SOUTHBOUND)

The existing noise barrier at this site consists of a wooden wall, 2700 ft. long and 13.5 ft. high. The wall was constructed in the spring of 1974 at a total cost of $181,000.

For the purposes of this example, consider a straight barrier, 2750 ft. long, extending between highway stations 745 and 772 + 50. Due to the limited right-of-way (30 ft. between edge of near lane and R/W limit), only one barrier position is considered. A design attenuation goal of 11 dBA is assumed for an observer location 61 ft. from the edge of the near lane along highway station 761. For the above conditions, the barrier nomograph procedure indicates a required barrier height of 12.5 ft. A profile drawing of the barrier site, indicating the source, observer and barrier locations, is given in Figure 5-1.

Selected design options for the chosen barrier locations are presented in Table 5-1. The table lists the barrier design codes and descriptions as well as the various constraints and additional treatment options. Note that an earth berm is not feasible in this case, due to space restrictions, and that a safety barrier is required, due to the close proximity to the highway.

The definition of cost factors for the various barrier design options is illustrated in Table 5-2. Total estimated costs for each option are also presented, referenced to the date and location of construction. A city index of 95 and an inflation index of 114.4 are assumed in the calculations.

The predicted costs for the wood barrier options are seen to be less than the actual cost. Note also that costs for the steel barrier options are much higher than the costs for the other material types.

SITE LOCATION

Allen Park, Michigan: I-75 (Southbound)
Highway Sta. 761

Scale: 1 in. = 10 ft.

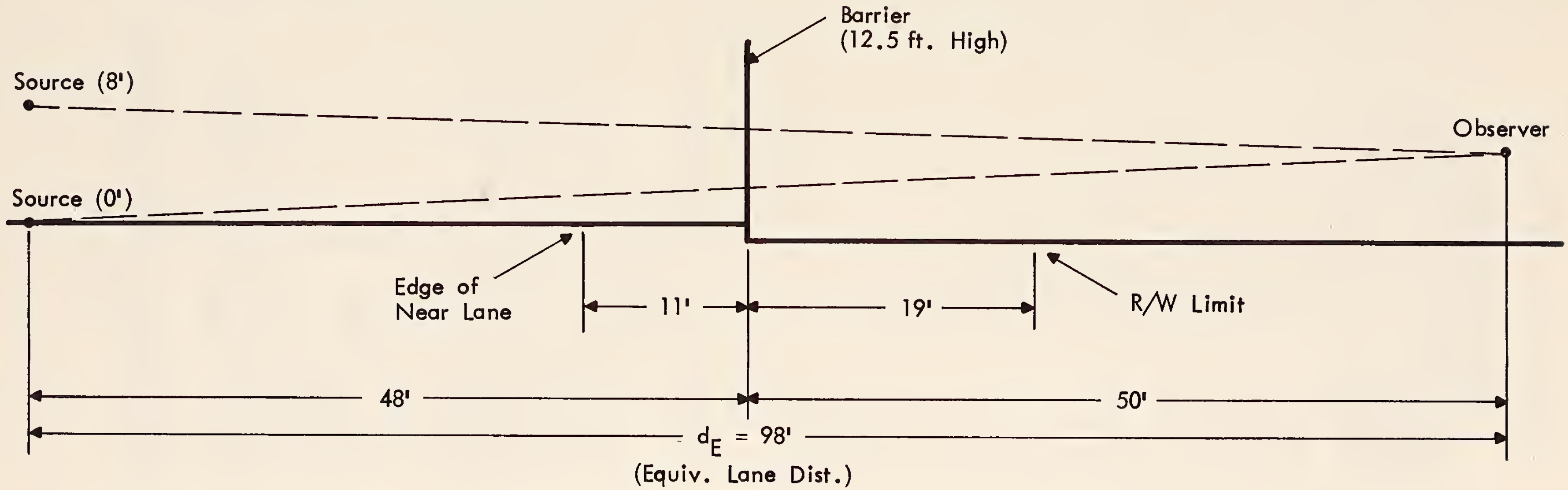


FIGURE 5-1. EXAMPLE 5 - BARRIER SITE PROFILE

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 11 /12.5 /2750	No. 2 / /	No. 3 / /
Pre-Cast	C-S		
	C-2-S		
	C-3-S		
Concrete	M-S		
Masonry	M-1-S		
Block	M-2-S		
Steel	S-5-S		
	S-5,1-S		
	S-5,2-S		
Wood	W-3-S		
	W-5,5-S		
	W-5,5,1-S		

Wind Loading	30 lb/ft^2	Safety Barrier	YES
Aesthetics	YES	Absorption	NO
Weathering	YES	Other Comments	

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED ?
C	Concrete untreated	NO
C-2	Concrete w/sandblast	NO
C-3	Concrete w/roughsawn random width board form	NO
M	Masonry untreated	NO
M-1	Masonry w/vertical scored block	NO
M-2	Masonry w/6" slump block	NO
S-5	Steel w/weathering	NO
S-5,1	Steel w/weathering + sheet metal trim	NO
S-5,2	Steel w/weathering + sheet metal trim & wood veneer	NO

TABLE 5-1. EXAMPLE 5 - BARRIER DESIGN OPTIONS

DESIGN OPTION WORKSHEET

LOCATION NUMBER

Position / Height / Length

MATERIAL	No. 1 11 / 12.5/ 2750	No. 2 / /	No. 3 / /

Wind Loading ____________ Safety Barrier ____________

Aesthetics ____________ Absorption ____________

Weathering ____________ Other Comments ____________

DESIGN CODE	DESCRIPTION	NOISE REDUCTION LIMITED?
W-3	Wood w/preservative	NO
W-5,5	Wood w/stain (both sides)	NO
W-5,5,1	Wood w/stain (both sides) + plywood facing	NO

TABLE 5-1. EXAMPLE 5 - BARRIER DESIGN OPTIONS (cont'd)

COST FACTOR WORKSHEET

Wind Loading 30 lbs. per sq. ft.

Design Code	Loc. No.	Ht. Ft.	Length Ft.	COST FACTORS Basic	Weather/ Aesthet. Treatmts	Safety Barrier	Absorptive Treatments	TOTAL	TOTAL COST
C-S	1	12.5	2750	69.55	--	12.08	--	81.63	186,300
C-2-S	1	12.5	2750	69.55	2.59	12.08	--	84.22	192,200
C-3-S	1	12.5	2750	69.55	8.34	12.08	--	89.97	205,400
M-S	1	12.5	2750	47.95	--	12.08	--	60.03	137,000
M-1-S	1	12.5	2750	47.95	6.47	12.08	--	66.50	151,800
M-2-S	1	12.5	2750	47.95	32.35	12.08	--	92.38	210,900
S-5-S	1	12.5	2750	103.33	3.17	12.08	--	118.58	270,700
S-5,1-S	1	12.5	2750	103.33	8.92	12.08	--	124.33	283,800
S-5,2-S	1	12.5	2750	103.33	16.69	12.08	--	132.10	301,500
W-3-S	1	12.5	2750	51.67	3.22	12.08	--	66.97	152,900
W-5,5-S	1	12.5	2750	51.67	4.36	12.08	--	68.11	155,500
W-5,5,1-S	1	12.5	2750	51.67	11.70	12.08	--	75.45	172,200

TABLE 5-2. EXAMPLE 5 - COST FACTOR DETERMINATION

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