Masonry Sound Barrier Walls and Fences
Written by Michael Schuller, P.E., Dave Woodham, P.E., & Diane Travis, LEED AP
Edited by Nancy Snyder

Published by
Rocky Mountain Masonry Institute

All rights reserved. Reproductions of all or parts of this publication may not be made without the expressed written consent of the publisher.

Printed in the United States of America.
Acknowledgements

Much of the information contained within this guide evolved from projects in and around Denver, Colorado. A simple masonry fence guide, developed for the City of Aurora in 2000, laid the groundwork for this project. The popularity of the City of Aurora masonry fence guide and frequent interest from organizations and individuals around the country was the inspiration to create a general publication to provide guidance and answer some of the typical questions for those embarking on a sound barrier wall project. Development of this Guide was made possible with a grant from the Council for Masonry Research.

The authors wish to thank the many individuals to whom we turned for ideas, answers, editing assistance, and photographs, including Olene Bigelow of the International Masonry Institute (Minneapolis office), Eric Johnson of the Brick Association of the Carolinas, Joan Borter of the Arizona Masonry Guild (Phoenix), Gregg Borchelt of the Brick Industry Association (Reston, Virginia), John Chrysler and Thomas Escobar of the Masonry Institute of America (Torrance, California), Bob Thomas of the National Concrete Masonry Association (Herndon, Virginia), and Rocky Mountain Masonry Institute members Walt Stivers of Basalite (Denver) and Brad Olson of Lakewood Brick and Tile (Lakewood, Colorado). Special thanks to Engineers Shan Wo and Alan Lockrem for their assistance in calculations and preparing data.

Michael Schuller, P.E.,
President, Atkinson-Noland

Dave Woodham, P.E.
Vice-President, Atkinson-Noland

Diane Travis, LEED AP
Technical Director, Rocky Mountain Masonry Institute
About the Authors

**Michael Schuller, P.E.** is a consulting engineer and president of Atkinson-Noland & Associates in Boulder, Colorado, with over 14 years experience, specializing in structural behavior, evaluation, and repair of masonry buildings. He has conducted several research projects for federal agencies and private firms, including investigation of procedures for masonry repair and methods for evaluating in-place masonry. Michael has over 55 publications relating to evaluation, repair, and structural behavior of concrete and masonry structures and is a co-author of a book titled *Nondestructive Evaluation and Testing of Masonry Structures*. He received a Master of Science Degree in Civil Engineering from the University of Colorado at Boulder.

**David Woodham, P.E.** is a consulting engineer and vice-president of Atkinson-Noland & Associates. He has published numerous papers related to evaluation of masonry structures, the instrumentation of experimental structures, structural behavior of civil structures, and corrosion detection in civil structures. David specializes in the application of nondestructive evaluation of civil structures. He is particularly experienced in the use of NDE techniques in historic structures including ultrasonic/sonic velocity measurement, impulse radar, and tomographic imaging. He received a Master of Science Degree in Civil Engineering from University of Colorado at Denver.

**Diane Travis, LEED AP** is the Technical Director for the Rocky Mountain Masonry Institute. Her background as a teacher and an architect prepared her well for her role as masonry industry advisor, troubleshooter, and lecturer. In addition to fielding nearly 2,000 technical calls each year from design professionals and contractors, Diane conducts the Institute’s outreach services, including: masonry design presentations to architects; informal job site consultations; reviews of conceptual and detail drawings; and development of periodic literature and case studies. Diane received her Masters degree in Architecture from the University of Illinois at Chicago, 1985. In 1990, she became a registered architect in Illinois. Prior to her arrival at RMMI, Diane was a project designer with Denver’s Daniel, Mann, Johnson & Mendenhall. Before that, she spent four years with the local firm of Klipp Colussy Jenks DuBois as a job captain on such notable masonry projects as the Denver Central Library.
# Table of Contents

1. Introduction ............................................................................................................................... 6
   1.1 Why Choose Masonry? ........................................................................................................ 6
   1.2 Masonry Walls Around the Country ...................................................................................... 7
      1.2.1 Minnesota: Highway Sound Barrier Walls ................................................................. 7
      1.2.2 Arizona: Residential Fences ......................................................................................... 8
      1.2.3 North Carolina: Highway Sound Barrier Walls .......................................................... 9
      1.2.4 California: Highway Sound Barrier Walls ................................................................. 9
      1.2.5 Colorado: Sound Barrier Walls and Fences ............................................................... 10
      1.2.6 Texas: “Thinwall” Fences ........................................................................................... 12

2. Design Considerations ............................................................................................................. 14
   2.1 Non-Structural Issues ........................................................................................................ 14
      2.1.1 Aesthetic Considerations ............................................................................................ 14
      2.1.2 Accommodating Movement ........................................................................................ 17
      2.1.3 Designing for Longevity ............................................................................................. 18
      2.1.4 Graffiti Issues ............................................................................................................. 19
      2.1.5 How Tall Should Your Wall Be? .................................................................................... 20
      2.1.6 Acoustic Performance .................................................................................................. 21
   2.2 Structural Systems .............................................................................................................. 22
      2.2.1 Cantilever ....................................................................................................................... 22
      2.2.2 Pier and Panel ................................................................................................................ 23
      2.2.3 Prefabricated Walls ........................................................................................................ 25
      2.2.4 Prestressed .................................................................................................................... 26
   2.3 Engineering Walls .............................................................................................................. 27
      2.3.1 Designing for Sound Reduction .................................................................................... 27
      2.3.2 Structural Design .......................................................................................................... 33
         2.3.2.1 Wall Geometry ......................................................................................................... 33
         2.3.2.2 Masonry Materials .................................................................................................. 34
         2.3.2.3 Design Forces ......................................................................................................... 34
         2.3.2.4 Analysis and Design ............................................................................................... 36
2.3.2.5 Deflection Considerations ..........................................................40
2.3.2.6 Foundation Design .................................................................40
2.3.2.7 Detailing .................................................................................42

3. Conceptual Designs .........................................................................44
3.1 Pier and Panel Walls .......................................................................44
3.2 Prefabricated Walls .......................................................................56
3.3 Cantilever Walls ...........................................................................60
3.4 Detailing Considerations ...............................................................69
   3.4.1 Finishing Your Wall with a Cap ..............................................69
   3.4.2 Details That Affect Structural Performance .........................70
   3.4.3 Changing Elevation and Terminating Walls .........................71
   3.4.4 Movement Joints ..................................................................72

4. Costs ...............................................................................................76
4.1 Designing for Economy .................................................................76
   4.1.1 Architectural Treatments .......................................................77
   4.1.2 Wall Type .............................................................................77
   4.1.3 Engineering Design ..............................................................78
4.2 Life Cycle Costs ...........................................................................79
4.3 Masonry Wall Costs ....................................................................81
4.4 Cost multipliers for various cities .................................................83
4.5 Escalation ....................................................................................84
4.6 Wall Cost Example ......................................................................85

5. Resources .......................................................................................88
Appendix ............................................................................................90
   Local, State, and Regional Masonry Associations ............................90
Introduction

This Guide presents information to help you design the best masonry wall for your project. It addresses issues faced by the design team – the owner, architect, structural engineer and sound engineer – when selecting a wall system. The section on structural systems will help you choose the best type of wall and foundation system for your local soils and weather conditions. The section on design considerations will help you evaluate different aesthetic possibilities. The section on conceptual designs has 10 different wall designs. Each wall type has a three-dimensional cut-away drawing that will help you understand how it is built. The final section on costs provides a “ball park” estimate of what it will cost to build your fence or sound barrier wall. It is difficult, if not impossible, to give accurate pricing information that will apply to the entire country. We have added some “local multipliers” that will help adjust generic pricing for a local market. The pricing section is best used to compare one local fence option with another.

1.1 Why choose Masonry?

Fences and sound walls are exposed to the harsh realities of weather 365 days a year. Buildings have only one side of the wall exposed to weather and daily temperature swings are mitigated by the central heating system. By comparison, fences are saturated, frozen and baked in alternating cycles. Fences are usually not maintained as well as building walls are. In other words, fences need to be tough to survive. Masonry is highly resistant to weather, abuse, and vandalism. The heavy-duty nature of masonry makes it the best choice for sound barrier walls.

Although wood fences and barriers are cheaper to build than masonry fences, they have a relatively short life span (15–20 years). Deteriorating wood fences can look pretty shabby even if they are structurally sound. Their weathered appearance can definitely hurt the “curb appeal” of a neighborhood.

Fences constructed with masonry materials not only last much longer than wood fences, they require little or no maintenance as they age. Brick, block and precast masonry fences can last 50–75 years if they are properly built. A good weather-shedding cap can make a wall last even longer.

Although precast concrete walls function and weather as well as masonry walls, brick and block walls are aesthetically more desirable. The texture, color and scale of the brick and block are an integral part of the product. The mortar lines and the subtle variation in color remind the viewer that he is looking at something constructed by hand. This rich visual palette can soften the monolithic appearance of a long, tall wall.
1.2 Masonry Walls Around the Country

Masonry sound barrier walls and fences are popular throughout the United States. There have been a number of highly successful projects completed in recent years. The following case studies provide examples of different types of masonry wall projects from around the country, including walls made of brick, concrete block and pre-stressed masonry construction. In addition to the specific examples provided below, masonry has become the focus of sound barrier wall activity in many other areas, including Boston, Chicago, Dallas/Fort Worth, Washington state, and Oregon, to name a few. Talk with a local masonry institute (see Appendix for contact information) to get more information, or just look around the area.

1.2.1 Minnesota: Highway Sound Barrier Walls

Concrete masonry sound barrier walls have been in place for over 30 years on I-94 through Minneapolis. They’ve lasted so well that the Minnesota Department of Transportation is using masonry as the material of choice for an extension of the existing wall. Dave Hall, an engineer with MNDOT, says that the walls “have stood up to the elements. All we’ve had to do was some repainting where we wanted to change the appearance.” Rather than using a continuous spread footing under the wall, the new design uses a cost effective “pier and panel” approach where the only foundations are under the columns. The Minnesota DOT calls for special requirements to combat the extreme Minnesota winters. They ask for high strength block and a water repellent surface coating to ensure long-term durability.
Some wood fences are still being built around Minneapolis, but there are concerns about health hazards from the preservatives used to slow wood rot. The older arsenic-based preservatives such as Copper Chromated Arsenate (CCA) have been banned by the EPA for residential use, and disposal of deteriorated wood is a problem. New ACQ (Ammonia cal Copper Quaternary) preservatives are less toxic but are still dangerous and more costly. Environmental experts have raised concerns about preservative chemicals leaching into the soil.

1.2.2 Arizona: Residential Fences

Concrete masonry walls and fences have become the norm in the Phoenix area. Nearly every new house built since the 1980’s has a block fence. The surface of the fence may be left with the block face exposed, stained, or coated with stucco, to blend in with the surrounding homes.

Sound barrier walls along highways usually use a decorative block, such as split face, ribbed, or integrally colored units. Very few wood fences are being built in the area, mainly due to the high cost of wood and the labor required. Some subdivisions are replacing their old wood fences with new masonry walls, to cut down on maintenance costs.

The market for dry-stacked (built without mortar) and post-tensioned masonry is especially strong in Phoenix. The cost–effective approaches reduce labor and material costs and are one of the reasons masonry fences are so popular in residential areas. Several proprietary wall systems developed in this area are beginning to be produced and marketed in other parts of the country.

The choice to use concrete masonry is based partially on appearance. Many walls use patterns and colors to complement the surrounding landscape. The concrete masonry walls also provide security. Some municipalities require masonry or wrought–iron fences around swimming pools to limit access.
1.2.3 North Carolina: Highway Sound Barrier Walls

Use of brick masonry is especially strong throughout North and South Carolina, with brick used on many residential, commercial and institutional buildings. Many owners choose brick fences and sound walls to complement their brick buildings. Some of the tallest brick sound barrier walls in the country are along the Raleigh Beltline highway. These walls, built using panels of utility brick (nominal dimensions of 4 x 4 x 12 inches) spanning 10 feet between reinforced brick columns, are up to 22–feet–tall. The wall design was developed using a value-engineering approach that showed brick walls to be considerably less expensive than precast concrete walls in the original design. The design was so well-received by the community that brick was specified as the material of choice for later Beltline sound wall projects.

The Raleigh Beltline Highway sound barrier wall

1.2.4 California: Highway Sound Barrier Walls

With many highways running through populated areas, it is no surprise that masonry sound barrier walls are popular throughout California. Nearly all of these walls are built with concrete masonry using ribbed units, integral color, and decorative patterns. These walls not only look great, but are also specially built to resist heavy shaking during earthquakes. The Los Angeles area division of the State DOT has settled on a standard design using 10-inch thick walls, with a double mat of vertical steel reinforcement every 8-inches on-center. These walls performed well during the 1994 Northridge earthquake. Even though they may look the same as walls built in other parts of the country, these walls are built with the extra strength and ductility needed for performance in high seismic risk areas.
1.2.5 Colorado: Sound Barrier Walls and Fences

Masonry has always had a strong presence in Colorado; and, the Denver area has many masonry sound barriers along its local highways. In recent years residents have turned to concrete masonry and California highway sound barrier walls combine decorative patterns with strength and ductility.

Colorado residents expressed a preference for the appearance of a split-face, integrally colored concrete masonry sound barrier wall.
brick walls to beautify their neighborhoods, provide security, and offer sound reduction along busy streets and highways. Masonry walls have been chosen over precast concrete panels because of their appearance. The warm textures and human scale of masonry are attractive to both homeowners and the highway builders who want to give a more personal feel to miles and miles of wall.

Many of the new highway sound barrier walls are built using split-face, integrally colored concrete masonry. The Colorado Department of Transportation funded a sample section of post-tensioned masonry wall as a demonstration project. Post-tensioned masonry walls need no grout in vertical cells, and the resulting lighter construction should lead to lower wall costs as this type of construction catches on.

The City of Aurora, a large suburb east of Denver, initiated a bond program to help neighborhoods replace worn-out wooden fences with masonry. Many of Aurora’s subdivisions were built in the 1970’s, and some homeowners were preparing to replace their wood fences – for the second time in 23 years. Aurora turned to the Rocky Mountain Masonry Institute for technical assistance because some members of the City Council felt that the miles of deteriorating wood fences lining their city streets were giving their town a bad image. They worked out a unique plan to help housing developments finance new fences in exchange for agreeing to replace the wood fences with long-lasting masonry ones.

Another Denver suburb, the City of Greenwood Village, has put up miles of new brick fences along its busy streets. The new walls help to block sound but also look great. The walls were built using brick, by choice, and provide a series of attractive corridors throughout the city.
1.2.6 Texas: “Thinwall” Fences

The pier and panel wall system makes sense in Texas, where movement of expansive clay soils has a tendency to crack walls built on spread footings. Hoggatt Masonry of Houston specializes in building masonry walls around subdivisions.

Mel Oller of Hoggatt LP explained, “When we can get people to sit down and look at life cycle costs, they decide to go with brick instead of wood or concrete. We like to use a King–Size brick for economics and ease of construction.”

King–size brick have a larger 3 x 10 inch face, but are somewhat thinner than a standard brick, measuring 2 5/8–inches deep. Because of their larger face size, and lower weight, walls built with King–size brick are erected faster and at lower cost than walls made with standard modular brick. This “Thinwall” concept is popular throughout the Houston area and is catching on in other parts of the country as well.

Texas Thinwall Fences are built with King–size brick.
2. Design Considerations

2.1 Non-Structural Issues

In addition to involving a structural engineer in a sound barrier wall project, it is also important to have an architect’s input. Architects usually take the lead in coordinating the project team. They are also responsible for ensuring the wall functions as desired and that the appearance meets everyone’s expectations. Their input is essential for making sure the end result of the project is an attractive, long-lasting wall with minimal future maintenance costs. Advice on how to address these “non-structural” issues follows.

2.1.1 Aesthetic Considerations

Unlike most masonry constructions which are seen and touched by pedestrians, sound barrier walls are usually seen from a distance at speeds of 50–75 miles per hour. Subtle details disappear at that speed, so it is important to include bold moves, strong textural changes and repetitive elements in the design.

To maximize the visual impact from design decisions, choose elements that give both functional and aesthetic effects. The piers in a pier and panel wall design are an integral structural part of the wall. The change in plane from the panel to the column also gives a deep shadow line. These columns break the wall into smaller pieces with repetitive vertical lines to punctuate the endless horizontal plane of the wall. A word of warning—some municipalities require a smooth surface on the traffic side of the wall. Check local building codes, zoning regulations and design guidelines. Home Owners’ Association regulations may also come into play.

A good weather-shedding cap can significantly extend the life of the wall. (See Section 3.4.1) A cap
that is 2 inches wider than the thickness of the wall panel creates a strong deep shadow line at the top edge of the wall. Rough-textured fluted, or split-faced, concrete block not only add visual interest to the wall, the rough texture also helps deflect and diffuse high pitched road noise. Both of these effects help to minimize the visual impact of dirt build-up over time.

Color is a basic and high-impact design choice. Brick has color throughout each unit. Concrete block can also have integral color, if the color is added to the block at the manufacturing plant. Since the sound barrier wall becomes an extension of the landscape, it usually looks best if the color is a close match with the earth tones in the area. One of masonry’s great benefits is that both sides of the wall have the same attractive finish.

Horizontal bands of color or texture are a natural design choice for long, horizontal walls. A simple decorative band can elevate the design from a utilitarian wall to a sophisticated one with very little additional cost. Brick accent bands can be achieved with a change in brick color or brick coursing (soldier courses). A subtle horizontal shadow line can be added by recessing one course of brick or block, but take care that the design idea doesn’t cause problems by exposing either the core holes of the brick or the horizontal reinforcing that gives the wall its strength. (See 3.4.2 for more information).

Designers inevitably face the challenge of how to vary the height of the wall as the surrounding countryside slopes up or down. When using a pier and panel design, change the wall height at the pier.
A wall height change at the top of a cantilever wall design breaks up the visual impact and keeps the bed joints level.

With a cantilevered wall design, change the top of the wall in steps, keeping the bed joints in the wall level.

Landscaping can make a great visual impact on a wall while wedding the masonry with the terrain. Choose native plants and grasses so that they will have the best chance of survival. Select species that take minimal or no maintenance. Along the base of a long highway barrier, group the landscaping near overpasses for maximum aesthetic appeal. For a neighborhood enclosure wall, take the same approach and group the landscaping around natural nodes like gates, corners and signage.
2.1.2 Accommodating Movement

All building materials move with changes in environmental conditions and masonry is no exception. Masonry expands and contracts in response to changes in moisture and temperature. This movement needs to be accommodated using either “control joints” or “expansion joints” to relieve built-up stresses and prevent unwanted cracks. As a general rule, concrete masonry shrinks over time, and designers use control joints to limit the development of shrinkage cracks. Brick masonry, on the other hand, typically expands as it ages and expansion joints are included in brick walls to accommodate this expansion.

Masonry wall designs must incorporate some provisions to accommodate long-term movement to limit crack formation. Control joints for concrete masonry are made by raking the mortar out of a joint on both sides of the wall. Because the wall is thinner at this point, it is also weaker.

Control joints along a masonry wall allow for brick expansion and block shrinkage.

Cracks will normally cut through this weakened section of the wall. Control joints do not actually prevent cracks, they simply control where they will occur. Expansion joints are required for brick masonry. An expansion joint must be totally open and free of anything rigid to permit the joint to close over time as the brickwork expands. Proper function of both types of movement joints requires that no horizontal reinforcement be permitted to cross the joint. A flexible joint sealant is typically used at the wall face to close the joint against moisture and sound transmission.
Designing joints to accommodate movement considers several factors, including the type of masonry involved (either concrete block or brick), wall height, expected temperature extremes, and the amount of reinforcement in the wall. Most walls will require movement joints spaced somewhere between 20- and 40-feet, depending on wall design parameters. See section 3.4.4 for more information on designing concrete masonry control joints and brick masonry expansion joints.

2.1.3 Designing for Longevity

One of the great attractions of installing a masonry wall is its ability to last year after year with virtually no maintenance. If properly designed and well constructed, masonry walls can be both beautiful and worry-free for decades.
The first place that a fence will deteriorate is just under the cap. The cap is the only horizontal surface on the wall. Snow and rain can sit on this ledge long enough to soak into the wall. In climates where the temperatures dip below freezing at night, the saturated masonry under the cap will fracture when the water turns to ice. Combat this action by installing a water-resistant cap like PVC or metal, or stop water migration by installing flashing between the cap and the wall. Flashing will interfere with the bond between the cap and the wall, causing the cap to shear off; however, shear plane failure can be overcome by installing masonry ties to hold the cap in place. With bitumen flashing under the cap, the tar in the flashing will self-heal the holes drilled to tie the anchors to the wall.

In a high seismic zone, install stainless steel stone anchors doweled into the ends of each cap piece to tie the cap to the wall below. In an area of low seismic risk, anchor the coping to the wall with a strip of expanded metal mesh installed above the bitumen flashing and fastened to the wall at 16-inches on-center. (See Section 3.4.1).

Provide weep slots at the base of the wall so that storm water can filter through the base of the wall. In arid climates it is usually adequate to simply leave the head joints open in the first course of masonry above grade. If the climate has more intense rain storms, leave bigger slots at the base of the wall. Neglecting to provide for storm run-off may result in the wall becoming a masonry swimming pool during an intense storm.

Although brick does not need a water repellent coating, it is a good idea to apply a water repellent to concrete block. When designing a block wall, specify the manufacturer incorporate an integral water repellent. This product is added to the concrete block mix during the manufacturing process. Integral water repellent is dispersed throughout the block and therefore coats both sides of the wall. Unlike spray-applied water repellents, integral repellents do not wear out, do not need reapplication and do not fade with age. It is important to follow the repellent manufacturer’s recommendations for the mortar on the job. Typically, the same additive is mixed into the mortar that was put into the block so that the mortar is compatible with the block.

Another option is to color the block with a penetrating masonry stain that will allow any moisture that gets into the masonry to evaporate. Unfortunately, most stains are transparent and will not cover up graffiti. If the wall must be painted because of graffiti issues, paint both sides of the wall using a masonry paint with a high water vapor transmission rating or a high perm rating. These ratings indicate that the coating will allow moisture to pass through the paint.

2.1.4 Graffiti Issues
Taggers like to leave their scribbled calling cards on walls where they hope everyone will see their signature but no one will be ambitious enough to clean it off. Sound walls are an inviting target because
they are very visible and appear to be undefended. Quickly removing graffiti discourages vandals who may move on to a less aggressively maintained property.

Applying a layer of invisible graffiti protection can make the job of cleaning graffiti much easier. The anti-graffiti coating prevents the marker or paint from penetrating deeply into the masonry and forming a permanent bond. Graffiti coatings can be sacrificial or non-sacrificial. The sacrificial coatings are removed when the wall is cleaned and need to be reapplied after each cleaning. Non-sacrificial coatings are more permanent, but all coatings get broken down by sun and weather so they need to be reapplied every few years.

The development of the ultimate graffiti coating is a constantly changing art. Contact a coating specialist to hear about the latest products on the market. Masonry walls need breathable coatings. A non-breathable coating will trap moisture behind the protective shield and the moisture will appear as a cloudy patch of efflorescence.

Some municipalities prefer to sandblast graffiti away. Concrete block can withstand sandblasting more easily than brick can. Concrete block is a steam-cured material which is homogeneous and does not change texture or color as you go deeper into the block. Brick, on the other hand, is fired. It develops a dense fire skin at the surface. This crust can be damaged by sandblasting, but repeated episodes of sandblasting will eventually damage even a block wall. Sandblasting makes the wall more porous and more susceptible to water damage.

Graffiti coatings are expensive. Save money by restricting the coatings to areas where vandalism is anticipated. On long highway sound walls, restrict the graffiti coatings to portions of the wall that are near overpasses, entrance ramps and exit ramps. Tagging is a pedestrian’s art. Identify the areas where a pedestrian can reach the wall to determine where to apply graffiti protection. If coating only a portion of a wall, make sure that the product does not change the appearance of the wall; some coatings may darken a wall or leave it shiny. If graffiti artists can detect graffiti coating, they may move just beyond the protected area to the uncoated wall. To evaluate how the coating affects the wall’s appearance, try applying the coating to a small area (at least 2-feet-square). Wait a few days for the coating to cure and see if there is a difference between the coated and uncoated areas.

2.1.5 How Tall Should Your Wall Be?

The ability of a masonry wall to block sound is a function of wall height — taller walls have a greater sound reduction capacity than shorter walls. But choosing a taller wall has structural implications as well: tall walls require more reinforcement, larger foundations, and are typically thicker than shorter walls.

Some building codes treat walls less than 12-feet-tall as “minor” structures and permit a design reduction in wind and earthquake load requirements. Check the local building code or talk to a local...
building official to see if the wall qualifies for a design approach using reduced loading.

Take the surrounding landscape and buildings into account when designing for wall height. Tall walls work best with mature landscaping and when placed some distance away from the roadway. Shorter walls often work better with residential developments. An extraordinarily tall wall will look out of place in the midst of a subdivision of single-story homes.

If the wall is also to act as a security enclosure keeping out unwanted visitors, it should be at least 8-feet-tall and have no projections that might serve as hand- or footholds. Where noise mitigation is not an issue, wrought iron fences are often used on top of masonry fences as an attractive means to provide added security without the imposing feel of a tall wall.

2.1.6 Acoustic Performance
The critical question for assessing the feasibility of a sound barrier wall is “how much would the proposed wall reduce the perceived traffic noise for a residential area located behind the wall?” In some cases, due to terrain or other influences, sound barriers of reasonable dimensions and cost will not achieve the desired sound reduction. In those circumstances, other remedies, such as reducing speed limits or limiting truck traffic, may be more cost effective solutions.

Sound is typically quantified in decibels because of the large range of sound intensity detectable by the human ear. In addition, the psychological sensation of loudness varies exponentially with increasing sound intensity rather than linearly. The decibel is a logarithmic unit used to describe a ratio of the measured sound intensity compared to a reference sound intensity (generally the threshold of hearing). In decibels, a doubling of sound intensity results in a change of 3 decibels (dB).

Most humans can detect sounds in the range between 20 to 20,000 Hz (vibrations per second), however, the human ear does not respond equally to all frequencies. Sounds in the frequency range from 1,000 Hz to 6,300 Hz are more readily detected than very low or very high frequencies. Because of this, highway noise sound measurements are weighted with a
frequency response similar to that of the human ear. Sound pressure level on the “A” sound level filter, denoted dB(A), is generally used in sound barrier wall design and sound pressure measurements.

Masonry sound barriers function by intercepting a portion of the sound energy between the source of the noise and the receiver. Some of the sound energy is absorbed, some is reflected, some is transmitted through the barrier, and some is diffracted (bent) by the top of the sound barrier as shown in Figure a. Lower frequencies are diffracted at a greater angle than higher frequencies. Figure b shows, conceptually, the various possible sound paths in the presence of a sound barrier. Specific information on designing a masonry wall for sound resistance is included later in Section 2.3.1.

2.2 Structural Systems

There are several types of masonry sound barrier walls, classified primarily by the way loads are transferred from the wall to the ground. A cantilever wall has a fixed base that prevents it from rotating at the base of the wall. Pier and panel walls are similar to a traditional fence with “posts” called piers and “rails” called panels. Variations on these two types of walls can be derived based on whether they are site-constructed, built off site, constructed with conventional reinforcement or post-tensioned with high-strength steel. The following describes different types of wall systems and presents some of the advantages and disadvantage of each wall type.

2.2.1 Cantilever

In areas with good soils and little or no existing landscaping, a cantilever type of wall is usually a good consideration. Cantilever walls transfer lateral forces from wind and earthquakes vertically, down to their foundation.

This Cantilever wall in California is designed to withstand an earthquake.
Cantilever walls get their strength and ductility from vertical reinforcement, which is grouted into the walls at regular intervals. Horizontal reinforcement is sometimes used to help with crack control but is not usually required as a component of a cantilever wall structural system.

Some type of continuous foundation is required under all cantilever wall types. A conventional spread footing is often used with cantilever walls but, because of the low weight of sound barrier walls, it is usually more cost-effective to use a narrow trench foundation under the wall. If drilled piers must be used (typically required in areas of expanding soils), it is still possible to build a cantilever wall type, but the wall must be supported by a continuous reinforced grade beam built just below the soil surface.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ No protruding columns, smooth faces on both sides of wall (safer wall for highway applications)</td>
<td>- Continuous footing needed: more disruption to landscaping, excavation costs can be higher</td>
</tr>
<tr>
<td>+ Conventional design, straightforward engineering, relatively easy to construct</td>
<td>- Can appear monotonous or stark if not given architectural considerations (such as varying unit colors, textures and height of wall)</td>
</tr>
<tr>
<td>+ Less quality control needed during construction (reinforcement and grout placed periodically during construction)</td>
<td>- More disruption to water drainage.</td>
</tr>
<tr>
<td>+ Cost effective for walls up to 14-feet tall</td>
<td>- More difficult to run utility lines under the wall</td>
</tr>
<tr>
<td>+ Can also be used as a retaining wall to hold back soil at changes in grade</td>
<td></td>
</tr>
</tbody>
</table>

### 2.2.2 Pier and Panel

Pier and panel wall systems are cost-effective and usually the best choice for most sound barrier wall applications. Wall panels are designed as deep “beams,” spanning horizontally between reinforced columns (or “piers”). The horizontal reinforcement in the panels turns each section of wall into a stiff, deep beam. Each end of this “beam” rests on a drilled pier which transfers loads into the soil. Reinforcement may be placed in grouted horizontal bond beams. A more cost-effective choice is the use of thin-gauge wires placed in horizontal bed joints as primary structural reinforcement. For most pier and panel wall designs, no vertical reinforcement is needed in the panel itself.
The piers act as the main structural element for this wall system; and, to minimize costs, most designs call for pier spacing between 12– and 20 feet. Piers are usually thicker than the wall. Piers may protrude from both faces as a column or be partially embedded within the wall as a pilaster. Vertical reinforcement is grouted solid within piers to transfer loads to the foundation. Regularly spaced piers also provide a convenient place to locate movement joints.

Pier and panel wall systems have foundations only at the piers, with the wall panel itself resting on a simple sand leveling bed or on cardboard void forms, used to prevent expansive soils from lifting the wall panel. The foundation itself may be a spread footing beneath the pier but it is usually cheaper to use caissons beneath each pier. Special drilling rigs are used to excavate soil for the pier. Reinforcement and concrete are placed in the hole to complete the foundation.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Efficient design. Wall panels can generally be built thinner than cantilever walls.</td>
<td>– Piers protrude from wall line. There is potential for vehicle catching on pier in highway applications. It is possible to build pilasters into the system, where the pier projects on only one side of the wall.</td>
</tr>
<tr>
<td>+ Cost effective. Reduced foundation requirements.</td>
<td>– Horizontal placement of steel in panels is critical and more inspection is usually required.</td>
</tr>
<tr>
<td>+ Major structural components concentrated at piers.</td>
<td></td>
</tr>
<tr>
<td>+ Less disruption to landscaping. Digging or excavation is needed only at pier locations</td>
<td></td>
</tr>
<tr>
<td>+ Less disruption to underground utility lines.</td>
<td></td>
</tr>
</tbody>
</table>

Advantages

- Efficient design. Wall panels can generally be built thinner than cantilever walls.
- Cost effective. Reduced foundation requirements.
- Major structural components concentrated at piers.
- Less disruption to landscaping. Digging or excavation is needed only at pier locations
- Less disruption to underground utility lines.

Disadvantages

- Piers protrude from wall line. There is potential for vehicle catching on pier in highway applications. It is possible to build pilasters into the system, where the pier projects on only one side of the wall.
- Horizontal placement of steel in panels is critical and more inspection is usually required.
2.2.3 Prefabricated Masonry Walls

Both cantilever and pier and panel masonry wall types can be prefabricated off site to simplify and speed the construction process. Pier and panel systems are especially well-suited for prefabrication as the wall panels can be dropped into place between columns. The choice to prefabricate walls depends on a number of factors, but this wall type is a good when trying to minimize disruption at the wall site. It is also a good choice for building walls during inclement weather. Contractors in some parts of the country have found this method to be cost-effective, particularly when existing landscaping complicates on-site construction.

Prefabricated masonry walls are built off-site, often in a warehouse or other sheltered location. After the panels are cured and stable they are trucked to the site where the wall panels are lifted into place by a crane or forklift. Columns may be built in place or prefabricated with structural connection to the foundations. On-site construction proceeds rapidly with this construction method.

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Good quality control in a production line setting.</td>
</tr>
<tr>
<td>+ Production rate and quality unaffected by weather.</td>
</tr>
<tr>
<td>+ Less traffic control needed due to reduced site work.</td>
</tr>
<tr>
<td>+ Less site disruption, noise, landscape damage in established neighborhoods.</td>
</tr>
<tr>
<td>+ Security maintained, as existing fences can be removed as wall panels are dropped into place.</td>
</tr>
<tr>
<td>+ Panels could be lifted and reused if road is widened in the future.</td>
</tr>
<tr>
<td>+ Cost savings realized by minimizing landscape damage and traffic closures.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Transport cost can be high if the panels are built far from installed site.</td>
</tr>
<tr>
<td>- A crane or forklift needed to place panels.</td>
</tr>
<tr>
<td>- Engineered design must consider lifting and transport stresses.</td>
</tr>
<tr>
<td>- Can be more expensive.</td>
</tr>
<tr>
<td>- Construction tolerances are tighter, requiring more coordination by project engineer/architect.</td>
</tr>
</tbody>
</table>
2.2.4 Prestressed

Somewhat new to the United States, prestressed masonry has been used for several decades in Europe. This structural system typically uses a series of threaded rods to provide a “clamping” force to tie the wall down to the foundation. Prestress rods are passed up through hollow units and then clamped in place. They can also be installed horizontally to reinforce wall panels in pier and panel design. An anchor plate and nut are placed over the end of the rod, which is tightened in place using either a calibrated torque wrench, a hydraulic jack, or with load-indicating washers placed between the nut and a bearing plate. Rods are usually unbonded and simply pass through hollow cells within the wall; grout placement in prestressed walls is typically limited to the anchorage zone beneath bearing plates. Some proprietary systems use prestress rods in walls laid without mortar, or “dry-stacked,” for substantial cost savings.

![Prestress rods are placed in hollow block units to reinforce the wall.](image)

### Advantages

+ Minimal grouting required
+ Takes advantage of the high compressive strength of masonry
+ Limits cracking as masonry is always in compression under service loads
+ Can be prefabricated off site

### Disadvantages

- New system in U.S. Many masons are unfamiliar with this type of construction.
- Construction tolerances tighter. Precise tendon placement is critical.
- Tendons and hardware are expensive. This cost may be offset by a reduction in labor and grout required.
Correct placement of prestressing rods is critical to avoid unwanted bending stresses, requiring precision placement to tolerances of ±¼ inch.

Design of prestressed masonry walls follows requirements of Chapter 4 of the Masonry Standards Joint Committee (MSJC) Building Code Requirements for Masonry Structures (ACI 530–05/ASCE 5/05/TMS 402/05). This section, incorporated into the Code in 1999, provides a series of requirements and approaches for designing prestressed masonry systems. To minimize dangerous corrosion effects, the MSJC code requires that all prestressing rods and hardware be galvanized or otherwise corrosion-resistant. This includes nuts, plates, rods, and couplers.

Most sound barrier wall designs strive to maximize either the wall height or the spacing between columns. As a result, engineering design is often limited by deflection of walls. Deflections are substantially reduced in prestressed walls because the tensioned rods are intended to prevent the walls from cracking. This makes the prestressed system especially attractive for use with sound barrier walls. Wall weights are also minimized due to minimal grouting requirements for prefabricated wall panel systems. Lighter panels means lighter lifting equipment.

2.3 Engineering Walls

There are many separate design parameters to achieve an efficient sound barrier wall design. The design engineer has to integrate the client’s sound reduction requirements for the wall, the type of masonry units selected, local soil and geological conditions, wind loads and seismic forces into a wall design that meets building code requirements for strength and serviceability. For additional guidance consult design guides and technical notes included in the resources list.

2.3.1 Designing for Sound Reduction

The basic procedure for designing a sound barrier wall incorporates the following steps:

1. Define sound reduction goals.
2. Define the site characteristics.
3. Design different sound barrier configurations to meet sound reduction goals.
4. Determine if additional architectural, safety or maintenance features are necessary. Evaluate acoustic performance of the wall.
5. Determine materials to be used and select specific design options.
6. Define costs for design options.
7. Assess aesthetics, durability, serviceability, safety, and other non-acoustic characteristic options.
8. Select the most appropriate sound barrier.
9. Optimize selected sound barrier design to minimize costs.
Step 1. Define Sound Reduction Goals

Determining the desired sound reduction is the first step in designing an effective sound barrier. Designing for sound reduction includes knowledge of the noise levels generated by traffic, the distance of the proposed sound barrier wall from the roadway and the location of the “receivers” such as homes. Existing sound levels are usually measured in the field at several locations. Noise levels can also be defined with computer modeling.

A properly designed sound barrier should be designed to reduce the ambient noise levels by at least 10 dB(A). This means that a person moving from the traffic side to the back side of a sound barrier will perceive that the noise level has been cut in half. The following table describes the relationships between different sound reduction amounts and the feasibility of attaining the stated sound reduction.

Table I. Sound Reduction Feasibility

<table>
<thead>
<tr>
<th>Barrier Sound Reduction</th>
<th>Level of Feasibility</th>
<th>Reduction in Acoustic Energy</th>
<th>Perceived Reduction in Loudness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 dB(A)</td>
<td>Simple</td>
<td>68%</td>
<td>30%</td>
</tr>
<tr>
<td>10 dB(A)</td>
<td>Attainable</td>
<td>90%</td>
<td>50%</td>
</tr>
<tr>
<td>15 dB(A)</td>
<td>Difficult</td>
<td>97%</td>
<td>65%</td>
</tr>
<tr>
<td>20 dB(A)</td>
<td>Nearly Impossible</td>
<td>99%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Once the geometry of the site has been determined, a series of calculations are conducted to determine the likely sound reduction of the proposed sound barrier wall.

In general, most sound barriers which interrupt the line of sight between the noise source and the receiver will have an insertion loss (IL) of 5 dB(A). Wall density will have an effect on insertion loss as well; massive, heavier walls are better at reducing low-frequency noise. The insertion loss is defined as the sound level at a given receiver location before the barrier was constructed minus the sound level at the same location after construction. Typically, each additional 2 feet added to the sound barrier above the line-of-sight increases the insertion loss by an additional 1 dB(A). This simplified analysis can be used to gauge whether the installation of a sound barrier is practical and warrants further exploration.

Step 2. Define Site Characteristics

This step involves investigating the impact of the proposed sound barrier on sight distance, its effect on elevated structures, the likelihood of the barrier being struck by a vehicle, likely impact on the community, and other factors unique to the site. In addition, wind or seismic design forces for the site should be determined and site-specific soil properties should be investigated. Hire a civil engineer to...
investigate sub-surface soil properties along the proposed wall alignment. This report will help determine the proper type of foundation and permissible foundation loads.

**Step 3. Design Different Sound Barrier Configurations to Meet Sound Reduction Goals**

Several alternatives should be developed for placement of the sound barrier alongside the road. For instance, a low wall placed close to the roadway would require a crash barrier while taller walls placed further from the roadway do not need crash protection.

Follow basic design procedures to determine the optimum barrier height, length, and setback from the roadway to achieve the required insertion loss. Calculate noise from cars and light trucks at roadway level. If heavy trucks are a significant portion of the vehicle mix, calculate their noise source at 8-feet above the roadway.

The barrier needs to be long enough to prevent sound from traveling around the ends of the barrier. In general, a barrier should be long enough to properly reduce unwanted noise if the distance between the end of the barrier and the last receiver is at least four times the perpendicular distance between the barrier and the receiver. Stated another way, the angle between lines drawn perpendicular between the receiver and barrier and the receiver and barrier end should be at least 76° as shown in Figure c.

Nomographs have traditionally been used to assist in the design procedure. Computer programs are also available to explore alternate designs (see AASHTO, *Guide Specifications for Structural Design of Sound Barriers*).

The simplest type of barrier analysis is based on the difference between the original (shorter) direct...
path between source and receiver and the increased path length of the diffracted sound between source and receiver. Simple graphs can be used to estimate the sound attenuation based on the calculation of the Fresnel Number for the geometry of the proposed sound barrier.

The attenuation can be expressed with help of the Fresnel Number, which is calculated by the formula:

\[ N_f = 2 \left( \frac{\delta}{\lambda} \right) \]

Where:

- \( N_f \) = Fresnel Number (dimensionless)
- \( \delta \) = path length difference, \( A + B - C \) (m or ft)
- \( \lambda \) = wavelength of particular sound (m or ft). For a representative frequency of 550 Hz, the wavelength will be approximately 0.60 m or 2.0 ft.

![Source](https://via.placeholder.com/150)

**Fig. d.** Path length difference (\( \delta \)) after insertion of a sound barrier is determined by subtracting path length C from the sum of the path lengths A and B

---

**Step 4. Determine if Additional Architectural, Safety or Maintenance Features are Necessary and Evaluate Acoustic Performance**

In this step, modifications to the sound barrier should be considered in response to local conditions. This may include improving the durability of the barrier for challenging environments, altering the appearance of the barrier to match local architectural styles, use of an anti-graffiti coating, and addition of a safety barrier or other site-specific modifications. In areas where barriers are to be built on both sides of the roadway, acoustically absorptive material may be needed on the roadway side of the barriers. This can still be masonry – use slotted units and patterned surfaces to minimize direct noise reflection. If barriers are to be built on both sides of the roadway, make sure that the space between barriers is at least 10 times the average height of the walls. If barriers are built too close together, reflection of sound between barriers can actually increase noise to receivers.
Step 5. Determine Materials to be Used and Select Specific Design Options

Transmission loss is greater with increasing density and thickness of the material. Another important consideration is the material’s surface texture; smooth panels reflect sounds while rough-textured masonry surfaces are better at scattering sound.

Table II provides a comparison of the approximate sound transmission loss for various sound barrier materials. In general, materials that weigh 4 pounds per square-foot or more will provide adequate transmission loss to ensure that the sound barrier can achieve a sound reduction of at least 10 dB(A). If the design sound reduction is 15 dB(A), then materials that have a transmission loss of 25 dB(A) or greater should be selected to achieve the designed reduction.

Table II Approximate sound transmission loss values for common materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (inch)</th>
<th>Weight (lbs/ft²)</th>
<th>Transmission Loss dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Block, hollow</td>
<td>4</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>Concrete Block, hollow</td>
<td>6</td>
<td>28</td>
<td>36</td>
</tr>
<tr>
<td>Modular Brick 3 5/8&quot; thick</td>
<td>4</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>Dense Concrete</td>
<td>4</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Light Concrete</td>
<td>6</td>
<td>50</td>
<td>39</td>
</tr>
<tr>
<td>Light Concrete</td>
<td>4</td>
<td>33</td>
<td>36</td>
</tr>
<tr>
<td>Steel, 20 ga</td>
<td>0.050</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>Steel, 24 ga</td>
<td>0.025</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Wood, Fir</td>
<td>0.5</td>
<td>1.7</td>
<td>17</td>
</tr>
<tr>
<td>Wood, Fir</td>
<td>1.0</td>
<td>3.3</td>
<td>20</td>
</tr>
<tr>
<td>Plywood</td>
<td>0.5</td>
<td>1.7</td>
<td>20</td>
</tr>
<tr>
<td>Plywood</td>
<td>1.0</td>
<td>3.3</td>
<td>23</td>
</tr>
<tr>
<td>Safety Glass</td>
<td>0.125</td>
<td>1.6</td>
<td>22</td>
</tr>
<tr>
<td>Plexiglas</td>
<td>0.25</td>
<td>1.5</td>
<td>22</td>
</tr>
</tbody>
</table>

Note that the values stated in the table above assume that there are no gaps or openings in the barrier material. Gaps permit sound to pass through the wall. Some materials, such as wood, can develop gaps due to shrinkage or cupping. Gaps between adjacent panels in prefabricated “stacked panel” walls should be avoided.
Step 6. Define Costs for Design Options

Assign a cost to each of the design options. The costs should include the structural foundations and a crash barrier, if required. An analysis of life cycle costs (Section 4.2) should also be included to provide estimated maintenance costs for each design option. It is also important to include costs associated with site work and landscaping, which often are a significant portion of the total project cost and can vary widely depending on the type of foundation used. Underground utilities may need to be moved to accommodate spread footings. Walls built with drilled piers can usually bridge over utility lines within the wall alignment. If an existing fence or wall is being replaced, some type of temporary fencing is often required for security purposes.

Step 7. Assess Aesthetics, Durability, Serviceability, Safety, and Other Non-acoustic Characteristics for Design Options

This step will rate the design alternatives with respect to the non-acoustical characteristics of the barriers. Aesthetics is a main consideration with publicly funded walls. Different alternatives should be evaluated by either a citizens’ panel or a team of designers. Durability and ease of maintenance (cleaning, repainting, graffiti removal, etc.) should be assessed for each alternate.

The impact of the barriers on snow removal should be assessed. In addition, tall barriers may shade the roadway at low winter sun angles creating a potential for icy spots. The assessment of the safety aspects of the wall may include evaluation of objects that could be dislodged from the wall in an impact. There is no real danger of dislodging individual brick or concrete block, but the impact safety of other wall components such as signs, lights and wall caps should be addressed.

Another aspect of the safety assessment would be to evaluate the consequences of a vehicle penetrating a relatively light barrier such as one made of wood. While not a major concern for reinforced masonry walls, a crash barrier may be required for walls built close to the edge of the roadway. Proper crash barrier design helps to deflect vehicle impact to protect vehicle occupants from serious injury. Crash barriers are required for many situations, depending on the roadway’s vehicle speed rating and distance of the wall from the driving lanes.

Step 8. Select the Most Appropriate Sound Barrier

Select a final barrier design, based on acoustic performance, cost, aesthetics, safety, durability, expected maintenance costs, community acceptance, and other factors.

Step 9. Optimize Selected Sound Barrier to Minimize Costs

Once the final barrier design has been selected, adjust the height and length of the wall to optimize sound reduction. Generally, computer modeling is done at this stage to evaluate multiple versions of the
final design to ensure that design objectives are met effectively and efficiently. The Federal Highway Administration’s Traffic Sound Model (FHWA TNM, available from McTrans Center, PO Box 116585, Gainesville, FL 32611-6585, or check http://mctrans.ce.ufl.edu) allows the user to explore multiple alternatives once the basic geometry has been entered into the program.

2.3.2 Structural Design

After adjusting the design to optimize sound reduction characteristics, the final wall design should be analyzed structurally to determine reinforcement and material requirements. Masonry sound barrier walls are engineered to meet minimum design requirements of American Association of State Highway and Transportation Officials or local building codes. The Masonry Standards Joint Committee (MSJC) Building Code Requirements for Masonry Structures (ACI 530-05/ASCE 5/05/TMS 402/05), referenced by the International Building Code (IBC), is used throughout most of the country.

Highway sound barrier walls may also need to meet the requirements of the AASHTO Guide Specifications for Structural Design of Sound Barriers. The AASHTO guide specification is generally more stringent than building codes. Many of the requirements of the AASHTO guide are based on the 1985 edition of the Uniform Building Code. AASHTO often requires greater wind and seismic loads than typical non-highway applications.

There are variables to be considered in the structural design of masonry sound barrier walls, including material strength, types of loads to be resisted, wall thickness, foundation type, and size and spacing of steel reinforcement. Designers should also consider how different parameters affect cost and constructability, optimizing the structural design to minimize construction costs. Wall thickness is a primary consideration, regardless of wall type, because thicker walls typically have greater material and labor costs than thinner walls. For cantilever masonry walls, the main structural components are vertically reinforced grouted cells. Costs are minimized if the distance between vertical reinforcing bars is maximized. For example, calling for #7 reinforcement at 4-feet on-center is cheaper than using #4 reinforcement at 16-inches on-center, even though both configurations provide the same steel quantity.

For pier and panel walls, much of the wall cost is associated with the piers and their foundations. The design should maximize column spacing. Typical column spacing ranges from 15– to 20-feet on-center. Deflections govern the design of tall cantilever walls or pier and panel walls with widely spaced piers.

2.3.2.1 Wall Geometry

Minimum wall height and thickness is usually dictated by sound reduction requirements as discussed previously. Structural design may require an increase in wall thickness. Major considerations that define wall layout are listed on the next page.
### Masonry Wall Design Considerations

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wall height</strong></td>
<td>Taller walls require more vertical structural steel and more substantial foundations but provide better sound isolation. Consider using architectural treatments to make tall walls appear less formidable.</td>
</tr>
<tr>
<td><strong>Wall thickness</strong></td>
<td>Thicker walls are generally stronger and have better sound reduction, but will cost more to build. Thinner walls (4– to 6–inches) are generally preferable for pier and panel systems.</td>
</tr>
<tr>
<td><strong>Pier spacing</strong></td>
<td>A wider pier spacing means fewer piers and drilled caissons, however each caisson will be required to carry more load and the panels will require more horizontal reinforcement as their span increases. The most cost–effective pier and panel systems have a wide pier spacing. A typical spacing is 15– to 20–feet between piers.</td>
</tr>
</tbody>
</table>

### 2.3.2.2 Masonry Materials

Both concrete block and clay brick can be used for sound barrier walls and the final material choice is usually governed by aesthetic and cost concerns rather than structural considerations. Brick is usually stronger than concrete block in compression, but for most reinforced wall systems the two material types perform equally. The choice of mortar to be used is also important. For most applications a Type N mortar is preferred; if greater flexural bond strength is necessary for increased structural strength it is also acceptable to use a Type S mortar.

The size of masonry units can also dictate structural capabilities for pier and panel wall systems. These walls are most cost–effective when reinforced panels have distributed reinforcement to maximize pier spacing. The designs call for horizontal reinforcement laid in the bed joint of each course of masonry. Walls built with taller units have fewer possibilities for placing horizontal reinforcement. In other words, there are more possibilities to install bed joint reinforcement in walls built using shorter units (4–inch block or modular brick). Such walls can span greater distances between piers. In general, it is more cost–effective to install horizontal joint reinforcement in each bed joint rather than use reinforced, grouted bond beams at a wider spacing.

### 2.3.2.3 Design Forces

Walls and fences are designed to resist loads prescribed by the local building codes. Building codes define how forces arising from dead loads (the weight of the structure itself), live loads, fluid pressure, wind, snow, lateral earth pressure, and seismic events are to be determined. Wind and seismic events generate the primary design forces for walls and fences. Where walls act as partial retaining walls lateral...
soil loads may govern the design.

Load combinations are used to investigate the worst loading case for the structure. For example, a sound barrier wall is typically subjected to its own dead weight, and either wind or earthquake loads (whichever is greater) to arrive at actual design forces. The small chance that a sound barrier wall would be subjected to high winds and an earthquake simultaneously is considered by building codes.

Vertical loads, due to the weight of the masonry itself, are considered in design but rarely govern the final design. Vertical dead loads are calculated based on the density of materials used. ASCE 7–05, Minimum Design Loads for Buildings and Other Structures lists typical material weights. Other good references include National Concrete Masonry Association (NCMA) TEK 14-13A for weights of partially and fully grouted concrete masonry walls, and Brick Institute of America (BIA) Technical Note 3B for section properties of reinforced brick masonry walls.

To design for wind loads, start with a lateral force calculated from the basic wind speed and adjust for the importance of the structure, the relative exposure at the building site and local terrain effects. Masonry walls and fences less than 12–feet–tall are normally considered to be a “minor structure,” and are designed to a lower load than a building or taller wall. Such walls are typically considered as a “Category I" structure, as defined by ASCE 7. They are designed for 77 to 87 percent of the wind load required for design of inhabited buildings. See Table 6–1 in ASCE 7 for importance factor requirements.

Earthquake loads are determined by the effective peak ground acceleration, soil conditions, the natural frequencies and internal energy dissipation of the structure, and the seismic performance category of the structure. Refer to the local building code for seismic design requirements. In most areas of the United States, wind loads will govern over seismic loads for sound barrier wall design.

Traffic impact loads are not normally considered in sound barrier design unless the wall is located on
a bridge structure or directly adjacent to a highway. For walls next to highways, the wall must be capable of resisting an impact load of 10,000 pounds, distributed over a length of 5 feet at a height of 2–foot–8–inches above the base of the wall. Another option is to build the sound barrier wall directly behind a crash barrier designed for impact loads. Impact loads for barriers on bridges are significantly greater and it is usually most economical to build the wall on top of a reinforced concrete crash barrier.

2.3.2.4 Analysis and Design

After defining the wall geometry, masonry materials to be used, and design loads, analyze the wall system to calculate the structural actions resulting from applied loads. For sound barrier walls, this process is fairly straightforward. The first step is calculation of vertical forces resulting from the dead load of the materials used to build the wall. Lateral shear and flexural moments arising from wind, seismic, or soil loads are also calculated.

Structural analysis and design follows the requirements of the MSJC or AASHTO codes. The MSJC code includes design criteria for allowable stress as well as strength design approaches; the AASHTO approach is somewhat dated, and based on allowable stress criteria from the 1985 Uniform Building Code. For most situations, use of the allowable stress criteria included in Chapter 2 of the MSJC code is appropriate for masonry sound barrier wall design. The MSJC code does permit increasing allowable stresses by one–third when using load combinations involving temporary wind or seismic loads, and it is important to apply this increase for sound barrier wall design. The MSJC code also includes requirements for the minimum amount of reinforcement (based on the seismic design category for the wall location) as well as the maximum reinforcement ratio, to provide proper ductility for resistance to lateral loads.

Cantilever Wall Design – A primary consideration for design of cantilever walls is horizontal flexure and shear at the base of the wall. Vertical reinforcement is used in grouted cells to resist lateral loads, and an efficient design strives to maximize the spacing of vertical reinforcement. It is not

Fig. e. Typical cantilever wall reinforcement design with force indicators.
necessary to have bars in every cell and most designs will use vertical reinforcement spacing in the range of 32– to 48-inches. For walls with a thickness of 8 inches or less, design vertical reinforcement to be a single bar, centered in the wall thickness. For 10– and 12–inch walls it is more efficient to place bars close to each wall face to maximize the bar’s effective depth within the wall. Refer to the local building code for minimum clearance required between the bar and unit face shell.

Horizontal reinforcement is not required to resist structural loads in cantilever wall designs, but horizontal joint reinforcement is used in concrete masonry construction to reduce the potential for shrinkage crack formation. Use of a reinforced bond beam at the top of the wall is also recommended to tie that part of the wall together. Intermediate bond beams are typically not required in masonry sound barrier walls.

**Pier and Panel Wall Design** – Pier and panel walls require a bit more design effort. The first step is to design the wall panel itself as a flexural member, spanning between piers, to resist lateral loads. The capacity of the wall panel to resist vertical and lateral shear loads should also be checked, but this requirement rarely governs wall panel design. Horizontal reinforcement may be either small–diameter wire, placed in mortar joints, or reinforcing bars in grouted bond beams placed periodically throughout the wall height. A few rules of thumb to follow when considering different types of horizontal reinforcement include:

- Use of joint reinforcement is usually more cost–effective than installing reinforced bond beams, especially for walls built with modular brick.
- For walls thicker than 8 inches, use of reinforced bond beams becomes more attractive. For these situations, use two bars in each bond beam, with the bars placed as near to each wall face as permitted by code.
- Even though it is more expensive, extra–heavy duty joint reinforcement (with 3/16–inch diameter side rods) is commonly used to optimize the wall span between piers.
- Joint reinforcement must have at least 5/8–inch mortar cover toward the wall face, for corrosion protection as well as to ensure proper bonding with joint mortar. Joint reinforcement should always be hot–dipped galvanized to meet building code and ASTM requirements.
- Joint reinforcement is made in standard widths of 2, 4, 6, 8, and 10 inches. Maximizing the width of the joint reinforcement for brick masonry, to optimize side wire placement as near to the wall face as possible, will often require custom fabrication and increased costs.
- For resisting its own weight, the wall panel acts as a deep beam, spanning from pier to pier. For walls built with movement joints at each pier, the panel is essentially simply supported and a reinforced bond...
beam is used at the bottom of the panel to resist flexural loads. Other wall designs may use multi-span conditions in which case bond beams are required at the bottom and top of wall panels to resist positive and negative bending moments. Walls built using reinforceable units will also have a bond beam at the top of the wall.

The second step in designing a pier and panel wall system is to design the piers themselves. The piers act as a vertical cantilever beam to resist loads delivered by the wall panels. Even though they have the appearance of a column, the piers usually have a low axial load and are designed as simple flexure elements. Piers are usually grouted solid, and, while vertical reinforcement may be placed within the main grouted center section, it is usually most effective to use bars placed in grouted cells near each pier face (Fig. f.).

Many pier and panel wall systems use an “I”-shaped pier, with the panel floating freely between the pier flanges. It is important to check shear through the flanges and in some cases the flanges may need to be reinforced. Metal ties between the pier facing and the solid grouted core augment the grout bond to transfer structural loads. Ties are also needed to resist the lateral pressure of fluid grout during construction. The MSJC code requires such ties be at least W1.7 and spaced no further apart than 24 inches up the pier height. (W1.7 ties are 9 gauge wire or 0.148 inches diameter.)

**Prestressed Wall Design** – Prestressed masonry relies upon vertical or horizontal rods, pre-loaded to provide a “clamping” force to resist lateral forces. One of the main advantages of this system is that deflections are reduced, compared to a conventionally reinforced wall, as a result of the prestress force. As discussed below, sound barrier wall design is often governed by deflection considerations, hence prestressed walls are typically designed for longer spans or taller heights than comparable walls built with grouted reinforcement.
Design criteria for prestressed masonry are somewhat new to the United States, first appearing in the 1999 edition of the MSJC Building Code. Additional information on designing prestressed masonry may be found in the Resources list at the end of this publication as well as in literature provided by manufacturers of prestressing system components. The main design task is determination of the force required in the prestress rod. This force is calculated to resist flexural stresses by keeping the wall section in compression. The calculated “final” prestress force is increased to account for losses resulting from the anchorage itself, bar relaxation, and creep, shrinkage or expansion, and elastic shortening of the masonry. A final check of the applied axial stress is made to ensure an adequate margin against Euler buckling.

The rod anchorage zone must also be designed to transfer forces from the prestress rod to the masonry. Some systems use plates designed to fit in recesses in special anchorage units, but it is more typical to have simple bearing plates resting on a grouted bond beam. Horizontally-spanning wall panels with horizontal prestress rods use grouted, reinforced vertical cells at each end of the wall to distribute prestress forces.

Sleeves are used to pass prestress bars through bond beams. The sleeves prevent grout from bonding to the free-floating bars.

Metal plates are placed periodically in mortar bed joints for two reasons: 1) to properly position bars at the wall center line; and 2) to provide restraint against movement as the wall deflects under load. Bar sections are coupled as construction progresses up the wall.
Prestress rods are normally “unbonded,” or placed in hollow cells without grouting. The current MSJC Code requires that unbonded rods be restrained from lateral movement within the cell. Grout or masonry is used at three locations along the rod’s length to help control eccentric prestress forces and the potential for buckling.

2.3.2.5 Deflection Considerations
For many sound barrier wall designs, deflection considerations actually govern the design rather than structural strength. The structural design process strives to maximize wall height or column spacing while minimizing wall thickness to save on material and labor costs. While this leads to an efficient wall design from a cost standpoint, considering only strength-related aspects of the design may result in walls with excessive deflection. The final structural design consideration is a check of the expected deflection of the wall system under applied loads.

Current building codes have limited discussion of deflection requirements for masonry walls. The MSJC code limits deflections of structural members carrying masonry (such as a steel lintel beam) to a deflection of the member span divided by 600 (or L/600). This is a good criteria for many building applications. Sound barrier walls, however, do not enclose habitable spaces, and generally some minor cracking can be tolerated. Designing sound barrier walls to limit deflections to L/600, where L is the height of a cantilever wall or the wall span between piers, is very restrictive and will lead to overly conservative designs.

Most masonry sound barrier walls and fences are designed to limit deflections in the range of L/180 to L/360. At this deflection limit, some minor hairline cracking may be observed during extreme load events. The reinforcement in the system will act to distribute cracks throughout zones of high flexural stress, preventing individual cracks from opening widely. Once loads are removed, such as will occur when high winds cease, the cracks typically close and are only visible upon close inspection. Most designs will tolerate a small amount of cracking, considering the infrequent nature of high wind and seismic loads. One final suggestion is that, with pier and panel wall systems, the piers are usually designed to a tighter deflection criteria, in the range of L/360, maximum, to prevent lateral pier deflection from inducing vertical flexure in the panel itself.

2.3.2.6 Foundation Design
All masonry sound barrier walls must have a foundation beneath the wall to transmit vertical and lateral loads to surrounding soils or bedrock. Foundations may be continuous (such as with spread or trench footings), but it is usually more cost effective to use intermittent drilled piers. A civil engineer will need to be involved to evaluate the type of soils along the wall alignment. A series of boreholes will be
drilled to investigate subsurface conditions, and some laboratory testing is usually required to identify the soil’s swelling potential.

Any type of foundation may be used in areas with non-swelling soils. If expansive soils are encountered, special deep foundations will be required to reach beyond the near-surface swelling soils to stable strata beneath. In these situations walls will be supported by drilled pier foundations. Wall segments between the drilled piers will be built on collapsible cardboard “void-forms” to prevent swelling soils from lifting wall panels.

Foundations are designed according to local building code requirements or AASHTO guidelines. The AASHTO sound barrier wall design guide includes a special commentary that describes approaches for designing several foundation types, including spread footings, trench footings, and drilled piers.

When using drilled piers to support masonry columns, some contractors choose to simply drill a larger diameter pier matching the column dimensions rather than using a small-diameter pier with a pier cap. The added expense of using additional concrete in the drilled pier is offset by the cost of forming, reinforcing and using special void-form material beneath a pier cap.

It is wise to conduct a soils investigation and locate subsurface utilities early in the planning process to define what type of foundation may be used and determine if utilities will be encountered along the wall alignment. Utilities are often placed in roadway right-of-ways, near the optimal wall alignment. Relocating underground utility lines is very expensive, and it is often better to adjust the wall alignment to miss utility locations. Another alternative is to design special foundations to cantilever or bridge over utility locations.

Wall spanning from caisson to caisson
2.3.2.7 Detailing
In addition to primary structural reinforcement designed to resist applied loads, a minimum quantity of vertical and horizontal reinforcement is required to meet seismic performance requirements. Section 1.14 of the MSJC code describes special requirements for seismic design categories A through F. In some situations it may be necessary to add reinforcement beyond that required for applied loads to meet these minimum reinforcement requirements.

Fig. g. Cantilever Pier Cap

Fig. h. Bridge Pier Cap over Utilities
Walls can take many forms and configurations, depending largely on the desired architectural appearance. Several sample wall designs are included here to provide an idea of variations in appearance and structural configuration that are possible using masonry walls constructed of concrete block or clay brick. Baseline cost information is included for each wall type to illustrate how different features and configurations affect construction costs. These costs are based on the Denver area for 2006 and do not include additional contractor costs as described in Chapter 4, which can be significant.

One important note: the designs contained in this publication are conceptual in nature and are not to be used for construction purposes. A local structural engineer must be involved to provide a final design that meets the local building code requirements.

3.1 Pier and Panel Walls

The first few conceptual wall designs use a “pier and panel” configuration where the wall panels are built as deep beams, spanning between foundations placed only below the columns. Panels are reinforced horizontally to carry loads to the columns. Movement joints at columns permit wall movement without cracking. Because there is no continuous foundation under this wall, it is often used in areas with expansive soils. It is also “landscape friendly” – columns with their foundations can be placed away from the root system of mature trees and shrubs.

### Advantages

+ Very efficient design; usually can be built thinner than cantilever walls
+ Cost effective
+ Disruption limited to surface landscaping – can work around trees and large bushes because digging needed only at pier locations.
+ Major structural components concentrated at piers

### Disadvantages

- Columns are required – these piers protrude from wall line, potential as a vehicle “catch point” in highway application
- More inspection required: horizontal placement of steel in panels is critical
Concrete Masonry Wall

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Concrete masonry units
- Type S mortar
- f'm = 2,000 psi
Concrete Masonry Wall

Construction and Cost Information

Column spacing: 20’-0”
Wall panel thickness: 6”
Column dimensions: 23¾” x 17¾”
Drilled pier size and reinforcement: 2’-0” diameter pier with (6) #5 vertical reinforcing bars.

Option 1: Horizontal Reinforcement in Mortar Joints
Wall panel reinforcement:

Not possible for this column spacing.

Option 2: Horizontal Reinforcement in Bond Beams
Wall panel reinforcement:

Bond beam with (1) #5 horizontal reinforcing bar, every 4th course @ 32” o.c.
Bond beam with (1) #5 horizontal reinforcing bar at top and bottom course.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bars in Column</th>
<th>Drilled Pier Depth (ft)</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4) #4</td>
<td>N/A</td>
<td>Option 1: $159.96</td>
</tr>
<tr>
<td>8</td>
<td>(4) #4</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>(4) #5</td>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>12</td>
<td>(4) #6</td>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>(4) #6</td>
<td>12</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Rocky Mountain Masonry Institute
Modular Brick Wall

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Clay masonry units
- Type S mortar
- f'm = 3,500 psi
Modular Brick Wall

Construction and Cost Information

Column spacing: 18'-0"
Wall panel thickness: 4"
Column dimensions: 15⅝" x 20"
Drilled pier size and reinforcement: 2'-0" diameter pier with (6) #5 vertical reinforcing bars.

Option 1: Horizontal Reinforcement in Mortar Joints
Wall panel reinforcement:
- W2.8, extra-heavy 3/16" diameter joint reinforcement, each course.
- Bond beam with (1) #3 horizontal reinforcing bar at top and bottom course.

Option 2: Horizontal Reinforcement in Bond Beams
Wall panel reinforcement:
Not economical for this column spacing.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bars in Column</th>
<th>Drilled Pier Depth (ft)</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Option 1</td>
</tr>
<tr>
<td>8</td>
<td>(4) #4</td>
<td>10</td>
<td>$172.78</td>
</tr>
<tr>
<td>10</td>
<td>(4) #4</td>
<td>10</td>
<td>$202.41</td>
</tr>
<tr>
<td>12</td>
<td>(4) #5</td>
<td>12</td>
<td>$232.04</td>
</tr>
<tr>
<td>14</td>
<td>(4) #5</td>
<td>12</td>
<td>$261.67</td>
</tr>
</tbody>
</table>
Stucco–Surfaced Concrete Masonry Wall

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Concrete masonry units
- Type S mortar
- f'm = 2,000 psi
Stucco-Surfaced Concrete Masonry Wall

Construction and Cost Information

Column spacing: 20’-0”
Wall panel thickness: 6”
Column dimensions: 23¾” x 17¾”
Drilled pier size and reinforcement: 2’-0” diameter pier with (6) #5 vertical reinforcing bars.

Option 1: Horizontal Reinforcement in Mortar Joints
Wall panel reinforcement:

*Not possible for this column spacing.*

Option 2: Horizontal Reinforcement in Bond Beams
Wall panel reinforcement:

Bond beam with (1) #5 horizontal reinforcing bar, every 4th course @ 32” o.c.
Bond beam with (1) #5 horizontal reinforcing bar at top and bottom course.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bars in Column</th>
<th>Drilled Pier Depth (ft)</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4) #4</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>(4) #4</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>(4) #4</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>12</td>
<td>(4) #5</td>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>(4) #6</td>
<td>12</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Hollow Reinforceable Brick Wall

**Material & Design Information**
- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Clay masonry units
- Type S mortar
- f'm = 3,500 psi
Hollow Reinforceable Brick Wall

Construction and Cost Information

Column spacing: 20’-0”
Wall panel thickness: 4”
Column dimensions: 17½” x 22”
Drilled pier size and reinforcement: 2’-0” diameter pier with (6) #5 vertical reinforcing bars.

Option 1: Horizontal Reinforcement in Mortar Joints (not shown above)
Wall panel reinforcement:
- W2.8, extra-heavy 3/16” diameter joint reinforcement, each course @ 3–3/16” o.c
- Bond beam with (1) #4 horizontal reinforcing bar at top and bottom course.

Option 2: Horizontal Reinforcement in Bond Beams (shown above)
Wall panel reinforcement:
- Bond beam with (1) #5 horizontal reinforcing bar, every 5th course @ 16” o.c.
- Bond beam with (1) #5 horizontal reinforcing bar at top and bottom course.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bars in Column</th>
<th>Drilled Pier Depth (ft)</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Option 1</td>
</tr>
<tr>
<td>8</td>
<td>(4) #4</td>
<td>10</td>
<td>$168.55</td>
</tr>
<tr>
<td>10</td>
<td>(4) #4</td>
<td>10</td>
<td>$184.74</td>
</tr>
<tr>
<td>12</td>
<td>(4) #4</td>
<td>12</td>
<td>$200.85</td>
</tr>
<tr>
<td>14</td>
<td>(4) #5</td>
<td>12</td>
<td>$216.88</td>
</tr>
</tbody>
</table>
Concrete Block Wall
with Hollow Structural Brick

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Concrete masonry units
- Type S mortar
- f'm = 2,000 psi
Concrete Block Wall
with Hollow Structural Brick

Construction and Cost Information

Column spacing: 20'-0"
Wall panel thickness: 6"
Column dimensions: 23½” x 17½”
Drilled pier size and reinforcement: 2’-0” diameter pier with (6) #5 vertical reinforcing bars.

Option 1: Horizontal Reinforcement in Mortar Joints
Wall panel reinforcement:

Not possible for this column spacing.

Option 2: Horizontal Reinforcement in Bond Beams
Wall panel reinforcement:

Bond beam with (1) #5 horizontal reinforcing bar, @ 32” o.c.
Bond beam with (1) #5 horizontal reinforcing bar at top and bottom course.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bars in Column</th>
<th>Drilled Pier Depth (ft)</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4) #4</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>$192.48</td>
</tr>
<tr>
<td>10</td>
<td>(4) #4</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>12</td>
<td>(4) #5</td>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>14</td>
<td>(4) #6</td>
<td>12</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Option 1 | Option 2
---|---
N/A | $192.48
N/A | $215.44
N/A | $238.42
3.2 Prefabricated Walls

Pier and panel wall configurations lend themselves well to prefabrication. Columns are either built in place or prefabricated. They are attached to drilled pier foundations using special bolted or welded connections. Wall panels built off-site are then lifted into place with a crane or forklift. These wall types give a great option when the construction time must be minimized or if walls may need to be moved in the future.

+ Good quality control in a production line setting. Production rate and quality unaffected by weather.
+ Less site disruption, noise, landscape damage in established neighborhoods.
+ Less traffic control needed due to reduced site work. Security maintained, as existing fences can be removed as wall panels are dropped into place.
+ Panels could be lifted and reused if road is widened in the future.
+ Cost savings realized by minimizing landscape damage and traffic closures.
+ Transport cost can be high if the panels are built far from installed site.
+ A crane or forklift needed to place panels. Engineered design must consider lifting and transport stresses.
+ Can be more expensive, but landscape restoration is cheaper.
+ Construction tolerances are tighter, requiring more coordination by project engineer/architect.
Prefabricated Wall

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Concrete masonry units
- Type S mortar
- f'm = 2,000 psi
Prefabricated Wall

Construction and Cost Information

Wall panel thickness: 6"
Column dimensions: 23½" x 17½"
Drilled pier size and reinforcement: 2′-0" diameter pier with (6) #5 vertical reinforcing bars.
Fence is assembled within 10 miles of site and trucked.

Horizontal Reinforcement in Bond Beams
Wall panel reinforcement:
Bond beam with (1) #5 horizontal reinforcing bar at top and bottom course of each 4′-0" tall prefabricated wall panel.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bars in Column</th>
<th>Drilled Pier Depth (ft)</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>(4) #4</td>
<td>10</td>
<td>$165.80</td>
</tr>
<tr>
<td>10</td>
<td>(4) #4</td>
<td>10</td>
<td>$188.10</td>
</tr>
<tr>
<td>12</td>
<td>(4) #5</td>
<td>12</td>
<td>$206.49</td>
</tr>
<tr>
<td>14</td>
<td>(4) #5</td>
<td>12</td>
<td>$231.12</td>
</tr>
</tbody>
</table>
3.3 Cantilever Walls

The following “cantilever” wall configurations have continuous foundations below grade with vertical reinforcing bars to resist wind loads. Vertical movement joints are placed periodically to accommodate wall movement and shrinkage without cracking. This conventional wall design is cost-effective for areas without problem soils.

+ Conventional design
+ Simple construction
+ No columns are needed: safer wall for use close to highways
+ Cost effective for walls up to 14-feet-tall
+ Continuous footing needed: excavation costs can be higher
+ Landscaping and underground utilities will be disturbed along the wall alignment, which will also add an expense to the total cost.
+ Creativity needed to break up the wall appearance. Use different block colors and textures. These techniques can also add a substantial cost to the wall.
Split-Face Block  
with Thicker Smooth-Face Block Base

**Material & Design Information**

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Concrete masonry units
- Type S mortar
- f'm = 2,000 psi
## Split-Face Block with Thicker Smooth-Face Block Base

**Construction and Cost Information**

Wall panel thickness: 6 inches
Vertical reinforcement in grouted cells.
Horizontal joint reinforcement for shrinkage control only.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bar Size and Spacing</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>#4 @ 48&quot; o.c.</td>
<td>$145.90</td>
</tr>
<tr>
<td>10</td>
<td>#5 @ 48&quot; o.c.</td>
<td>$169.67</td>
</tr>
<tr>
<td>12</td>
<td>#6 @ 48&quot; o.c.</td>
<td>$193.44</td>
</tr>
<tr>
<td>14</td>
<td>#6 @ 24&quot; o.c.</td>
<td>$217.21</td>
</tr>
</tbody>
</table>
RMMI Sound Wall Guide

Split-Face Block
with Highway Crash Barrier Base

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Concrete masonry units
- Type S mortar
- f'm = 2,000 psi
Split-Face Block
with Highway Crash Barrier Base

Construction and Cost Information

Wall panel thickness: 6 inches
Foundation: continuous reinforced concrete spread footing, foundation wall, and crash barrier.
Vertical reinforcement in grouted cells.
Horizontal joint reinforcement for shrinkage control only.

<table>
<thead>
<tr>
<th>Wall Height Above Crash Barrier (ft)</th>
<th>Vertical Reinforcing Bar Size and Spacing</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>#4 @ 48&quot; o.c.</td>
<td>$143.35</td>
</tr>
<tr>
<td>8</td>
<td>#5 @ 48&quot; o.c.</td>
<td>$160.49</td>
</tr>
<tr>
<td>10</td>
<td>#6 @ 48&quot; o.c.</td>
<td>$186.63</td>
</tr>
<tr>
<td>12</td>
<td>#6 @ 16&quot; o.c.</td>
<td>$212.77</td>
</tr>
</tbody>
</table>
Two-Wythe Brick Cantilever Wall

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Clay masonry units
- Type S mortar
- f'm = 3,500 psi
Two-Wythe Brick Cantilever Wall

Construction and Cost Information

Wall panel thickness: 10 inches
Foundation: continuous reinforced concrete spread footing, with reinforced concrete masonry foundation wall.
Vertical reinforcement placed in fully grouted space between brick wythes.
Horizontal reinforcement in bond beam at top of foundation wall.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bar Size and Spacing</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>#4 @ 48&quot; o.c.</td>
<td>$252.00</td>
</tr>
<tr>
<td>10</td>
<td>#4 @ 48&quot; o.c.</td>
<td>$304.00</td>
</tr>
<tr>
<td>12</td>
<td>#5 @ 48&quot; o.c.</td>
<td>$356.00</td>
</tr>
<tr>
<td>14</td>
<td>#6 @ 48&quot; o.c.</td>
<td>$384.00</td>
</tr>
</tbody>
</table>
Hollow Reinforceable Brick Cantilever Wall

Material & Design Information

- Meets the requirements of the 2003 IBC
- Design wind load = 13.3 psf
  - Basic wind speed = 90 mph
  - Exposure = C
- Clay masonry units
- Type S mortar
- f’m = 3,500 psi
RMMI Sound Wall Guide

Hollow Reinforceable Brick Cantilever Wall

Construction and Cost Information

Wall panel thickness: 6 inches
Foundation: continuous reinforced concrete spread footing, with reinforced concrete masonry foundation wall.
Vertical reinforcement placed in grouted cells.
Horizontal reinforcement in bond beam at top of foundation wall and top of wall.

<table>
<thead>
<tr>
<th>Wall Height (ft)</th>
<th>Vertical Reinforcing Bar Size and Spacing</th>
<th>Cost ($ per lineal foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>#5 @ 48&quot; o.c.</td>
<td>$170.40</td>
</tr>
<tr>
<td>10</td>
<td>#6 @ 48&quot; o.c.</td>
<td>$204.20</td>
</tr>
<tr>
<td>12</td>
<td>#6 @ 16&quot; o.c.</td>
<td>$238.00</td>
</tr>
<tr>
<td>14</td>
<td>#6 @ 8&quot; o.c.</td>
<td>$271.80</td>
</tr>
</tbody>
</table>
3.4 Detailing Considerations

3.4.1 Finishing the Wall with a Cap

Although the wall cap constitutes less than 5 percent of the wall, a well-built cap can nearly double the life of the wall. The cap is important because it is the only horizontal exposure in the wall. The first place a masonry wall will start to deteriorate is the cap. If the water penetration can be stopped at the cap, it will stop the damage. This is particularly important in areas with aggressive freeze–thaw cycles.

A smooth mound of sloped mortar is a common wall cap, but this detail is not recommended. Although it is one of the cheapest options, it simply does not shed water well. It is rarely sloped steeply enough to encourage water to run off the wall. In addition, mortar caps are absorptive and they inevitably have shrinkage cracks that allow water to seep into the wall. Although it is less expensive than most other options, a smear of mortar on top of the wall is simply not a good value.

Another wall cap that doesn’t last well is a flat concrete block cap. Most concrete block is just too absorptive to be used as a cap. When it doesn’t slope at all, it is inviting efflorescence and deterioration. Only use a CMU soap as a cap in extremely hot, dry climates with no risk of water penetration.

A good water–shedding cap is made of metal or PVC. Although these materials might seem incongruous to a purist, they are watertight, long–lasting, cost effective, and functional. They usually come in 10–foot sections; pay attention to the joints in the system to make sure they can accommodate slight differential movement and remain watertight.

Slabs of stone or precast concrete make excellent wall caps because they are usually quite water repellent and have relatively few joints. Mortar joints are always the first place where the cap breaks down. Stop this initial failure by raking the horizontal joints between cap stones back ½ inch and filling the notch with flexible sealant.

Some block manufacturers make decorative cap blocks for topping off a masonry wall. Unlike typical stretcher blocks, these cap blocks have no holes. They are 100 percent solid. They also have a steeply sloped top surface—typically a 45–degree angle. These cap blocks are sometimes called Monopoly blocks because they resemble the little hotel blocks in a Monopoly set.

To use a course of rowlock brick as the top cap of a wall, install thru-wall flashing under the brick cap to keep water from seeping into the body of the wall. This flashing provides a plane of weakness if the wall is hit with something (like flying debris or a skateboarder) and the entire cap can shear off in one piece. To combat this weakness, install a strip of galvanized expanded metal mesh in the bed joint just above the bitumen flashing. Attach this mesh to the wall with TapCon anchors and washers at 16–inches on–center. In an area with a high likelihood of earthquakes, install stainless steel stone anchors with
dowel pins that engage the holes in the brick. In an area where earthquakes are mild or rare, the expanded metal mesh will provide the necessary grip between the rowlock cap and the wall. Use a bitumen–based flashing under the brick cap. Bitumen has some stickiness and resistance to shear–plane failure. Also, the tar in the flashing melts when the sun comes out and can self–heal the small holes created when the masonry ties are screwed through the flashing into the wall below. Because the bitumen in the flashing melts, cut this flashing back ½–inch from either face of the wall to avoid tar runs dripping down the face of the wall.

3.4.2 Details That Affect Structural Performance

Although most sound walls are simple, unadorned brick or block fences, a little embellishment can significantly add to the appearance of the walls. The least expensive option is to simply add a horizontal stripe. This accent band can be a change in color, a change in texture or even a recessed band of masonry that adds a continuous shadow line to the wall. Be careful that the accent band does not significantly weaken the wall.

Since these tall, thin masonry walls get much of their strength from the horizontal reinforcing buried in the bed joints, some aesthetic wall choices can actually affect the strength of the wall. If the design calls for a band of soldier course brick, the horizontal reinforcing cannot be installed at the usual intervals because it would weaken the wall. Some engineers call for a denser reinforcing pattern on the bottom third of the panel to achieve a deep, stiff beam with the masonry panel that spans from pier to pier. This stiff beam resists the gravity loads on the wall. A soldier course near the bottom of the wall might significantly weaken the panel while an accent band near the top of the wall has minimal effect.

A cantilever wall gets its strength from vertical rebar grouted into the cores of the block or the structural brick. Some accent stripes like a soldier course or a band of stone can make it difficult to install the rebar.

Changing the plane of the wall to create a shadow can cause some problems for the construction crew and structural engineer. Changing the location of the bed joints also affects the size and location of the horizontal reinforcing. Building codes (IBC 2104.1.3) require a minimum cover of 5/8–inch from the face of the wall that is exposed to weather to the centerline of the horizontal reinforcing rod. Since this is a fence, both faces of the wall are exposed to weather. Building it with 3–5/8" thick bricks, indicates the horizontal reinforcing can be no bigger than 2–1/4” wide (See Figure i–1).

If the corbel is offset by ¾-inch, the reinforcing is narrowed to 1 1/2–inch. (See Figure i–2). This change in depth affects the ability of the wall to resist lateral wind loads. If queen–sized brick is used for the recessed band (See Figure i–3), the size of the reinforcing is reduced to 1–1/4”. Changing from 4–inch deep brick to 6–inch and 8–inch deep units to construct the shadow lines will not cause any
structural problems because it will not narrow the width of the horizontal reinforcing (See Figure i–4).

Horizontal reinforcing that is narrower than 2 inches is not commonly available. Use instead two lines of pencil rod. Pencil rod is a line of horizontal reinforcing without cross wires. Without the cross wires, the lines of pencil rod can be installed at any spacing that works for the wall.

If the wall is being constructed of queen-sized bricks, there is an unusually thin plane of masonry. Queen bricks are 2–5/8 inches wide. A corbel cannot be used with such a thin wall.

If the wall is being built with concrete block, grout the CMU solid below and above the offset block so that the mortar holding the horizontal reinforcing in place has something to attach to. Typically, concrete block walls are thick enough that they can accept a corbelled or recessed band without affecting the structural capability of the wall.

3.4.3 Changing Elevation and Terminating Walls

Entries to subdivisions or wall terminations at crossing streets require special attention, not only for architectural reasons, but to also provide proper sight lines for vehicles approaching.

The subdivision entrance is set back from the entrance and the wall height steps down to allow drivers to see oncoming traffic.
intersections. A good rule of thumb is to pull walls back at least 30 feet from the intersection. This important safety feature is often written into municipal zoning requirements.

In elevation view, a wall that simply ends at full height often appears awkward. A better choice is to gradually decrease the wall height using a series of steps or a gradual transition.

### 3.4.4 Movement Joints

Masonry walls and fences often run for long distances – in some cases for many miles. Changes in temperature and moisture content will cause walls to expand and contract, and it is important to have movement joints to accommodate these natural movements and limit cracking. Movement joints are especially important in pier and panel wall systems. They help to keep wall panels from cracking if the column foundations move.

Effective movement joints use flexible sealants to keep out sound and water. Information on the design and spacing of movement joints is found in BIA Technical Note 18A and NCMA TEK 10–1A. Included here are some simple details to show basic movement joint requirements.

**Brick Expansion Joint** –

Expansion joints are used to accommodate thermal and moisture-related brick growth and must be free of all obstructions such as mortar, grout, or reinforcement. In pier and panel walls and fences, brick expansion joints are best located at columns. Expansion joints in cantilever walls are installed at a regular spacing, typically at about 25– to 30– feet on–center.

![Control and Expansion Joint Detail](image-url)
Concrete Block Control Joints – Control joints for concrete masonry are simply weak points in the wall that force cracks to occur at a controlled location as the wall shrinks. Three types of control joints for use in cantilever walls are shown below. They are usually placed at 25- to 40-feet on-center. Cut horizontal rebar and bed joint reinforcement at control joints. Locate these joints where the panel meets the pier.
4. Costs

The prices stated below include material costs, labor costs, equipment, taxes and permit fees, as well as overhead and profit for the contractor.

In order to estimate the cost of the wall, the cost of the chosen wall type is used as the base price. Various options will then add costs (or in some cases, subtract costs) from the base price, arriving at the wall cost in 2006 dollars provided the wall were to be built in the Denver area. In order to translate these costs to different markets and to adjust for inflation, market cost factors and inflation factors will be used to modify the 2006 Denver cost.

Although the cost of all sound barrier walls is substantial, masonry sound barrier walls tend to add value to residential properties shielded by the sound barrier walls. This effect is dependent upon the aesthetics of the wall design, the acoustic performance, wall height, and proximity to the properties.

<table>
<thead>
<tr>
<th>Block type</th>
<th>Additional cost (per square foot of wall)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split face, 1 side only</td>
<td>$0.73 per square foot</td>
</tr>
<tr>
<td>Split face, front and back</td>
<td>$1.57 per square foot</td>
</tr>
<tr>
<td>Split face with ribs, 1 side only</td>
<td>$1.35 per square foot</td>
</tr>
<tr>
<td>Ground face, 1 side only</td>
<td>$1.35 per square foot</td>
</tr>
<tr>
<td>Integral color</td>
<td>$0.84 per square foot</td>
</tr>
<tr>
<td>Integral water repellent</td>
<td>$0.79 per square foot</td>
</tr>
<tr>
<td>Paint*</td>
<td>$1.50 per square foot per side</td>
</tr>
</tbody>
</table>

* Includes costs for initial treatment; repainting required at 7 to 10 year intervals.

Table III. Representative costs for various concrete masonry unit treatments, based on a smooth gray 6-inch-thick block cost of $1.13 per square foot of wall area (Denver area, 2006).

4.1 Designing for Economy

There are many decisions that must be made for a masonry sound barrier project to be successful. Weigh all options carefully because the overall project cost will be affected by each design choice. For example, a taller wall blocks more noise than a shorter wall, but a taller wall will also require more structural
reinforcement and will be more costly than a shorter wall. Entering the design process with a good understanding of the conditions on site, the required level of noise reduction, and the desired final appearance will help to ensure an accurate project budget. Use the cost information in this section wisely; the listed costs are best used as general indicators of expected costs or to compare different wall designs rather than as absolute prices. Contractor costs will vary depending on the season, the local economy, and material costs.

4.1.1 Architectural Treatments

The choice of a cap greatly affects the life span and maintenance of the wall. (See section 3.4.1) It also affects the price as shown in the table below.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Cost (add or subtract from wall costs listed for each of the conceptual designs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick soldier course</td>
<td>$14.35 per linear foot</td>
</tr>
<tr>
<td>Wall cap</td>
<td></td>
</tr>
<tr>
<td>Precast concrete (wall cap, 8x4 with pitched top surface)</td>
<td>$28.61 per linear foot</td>
</tr>
<tr>
<td>Flagstone (8x2 with snapped edge)</td>
<td>$31.00 per linear foot</td>
</tr>
<tr>
<td>Concrete masonry (lightweight standard concrete masonry, 8x4 with pitched top surface)</td>
<td>$10.30 per linear foot</td>
</tr>
<tr>
<td>Brick rowlock</td>
<td></td>
</tr>
<tr>
<td>Metal (20 ga. field painted metal cap)</td>
<td>$6.17 per linear foot</td>
</tr>
<tr>
<td>Mortar wash</td>
<td></td>
</tr>
</tbody>
</table>

Table IV. Representative costs for various masonry unit treatments

4.1.2 Wall Type

A main advantage of masonry construction is the sheer variety of design options available. Concrete units can be plain gray, colored, glazed, split-face or scored. They can have recessed or beveled faces to create patterns in a wall, or flutes to change the texture of the wall. Mixing specialty finishes with smooth-faced block can break up the monotony of a large wall. The use of units with significant texture can improve the acoustic performance of the sound barrier.
Brick are available in a wide variety of sizes, textures and colors. In addition, a variety of bond patterns can be used to provide texture and variety and visual interest to a wall. English, Flemish, stack, and garden wall bond provide visual appeal while soldier or rowlock courses provide accents. Adhered stone is also an option.

### 4.1.3 Engineering Design

The economy of a sound barrier is usually dictated by the engineering requirements. Since labor costs often account for more than 50 percent of the cost of the wall, reducing labor can significantly affect the final cost of the wall. Several design concepts which reduce labor costs should be considered as they can help reduce the overall cost of the wall.

1. Specify large diameter reinforcing bars at a maximum spacing in the wall. For example, the use of #6 reinforcement at 48-inches on-center requires one-half the number of grouted cells as #4 reinforcement at 24-inches on-center yet provides an equivalent quantity of structural steel per linear foot of wall.

2. For walls up to 8 inches thick, it is cheapest to design for a single reinforcement layer placed along the wall centerline. The benefit of using double reinforcing layers, with bars placed near each wall face, is effective only with 10- and 12-inch-thick walls.

3. Whenever possible, dimensions (wall length, wall height, wall openings, or returns) should be designed to be built with full and half-length units to minimize cost and waste associated with cutting units. Designing properly to an 8-inch "masonry module" will help keep wall costs down.

4. The wall cap protects the wall from moisture and it is important that it be impermeable. Install a through-wall flashing under the wall cap. Preventing moisture from entering the masonry is essential to the long-term performance of a masonry sound barrier and will reduce future maintenance costs.

5. Minimize foundations and column elements. Foundations are relatively expensive in comparison to the above-grade wall. For pier and panel systems, maximizing the column spacing will reduce costs substantially. For example, increasing the pier spacing from 12- to 16 feet will result in 25 percent fewer columns and caissons.

6. Thinner walls can save both material and labor cost and result in lower weight walls and smaller foundations. Thinner walls generally require more grouting and reinforcement so the ideal compromise is to design a wall thickness that is adequate without requiring excessive additional labor.

7. Use lightweight concrete masonry units. Labor is a major cost component of any masonry
project, and mason productivity governs in-place wall cost. Lightweight units may cost slightly more than normal-weight units, but masons can lay more lightweight units than normal-weight units in a day, reducing installation costs. Normal-weight block are usually used only when required for extreme structural or sound-reduction applications.

8. Similarly, design walls using larger queen- and king-size brick instead of smaller modular brick whenever possible. The larger size of these units result in greater mason productivity, typically reducing overall costs.

4.2 Life Cycle Costs
In comparing the cost of various wall types, give careful consideration to the Life Cycle Cost Analysis (LCCA). The following data should be considered in calculating life cycle cost:

1. the initial cost of the wall
2. the expected service life of the materials in the wall
3. interest rates (the time value of money)
4. expected inflation or escalation rate
5. the expected maintenance costs over the life of the wall

Standard engineering economy principles are used to rank alternative materials and methods of construction. The simplest method is to bring all future costs back to the time of construction considering the reduced future purchasing power of today’s dollars. As expected, walls with a low initial cost and a long service life will have a minimum life cycle cost. In reality, many materials with a low initial cost do not provide a long service life, leading to increased life cycle costs.

Life cycle cost analysis is only as good as the available data. Construction costs are typically available for new noise barriers but vary widely from project to project based on many factors (see Table V) such as the location of the project, landscaping costs, project size, and architectural treatments. In most cases, historical data is not available for maintenance costs for noise walls of different materials. Further, the service life of noise barriers is generally an estimate. There is very little reliable historical data.

Maintenance of masonry may involve the following:

1. repointing of occasional cracks or damaged mortar joints, every 20 to 25 years
2. graffiti removal
3. repairing impact damage
4. repair or replace wall caps
5. periodic cleaning
Table V. Cost data and quantity constructed by year for noise barriers from Colorado Department of Transportation’s Cost Data Books.

<table>
<thead>
<tr>
<th>Year</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier Type</td>
<td>Cost/ft² (ft²)</td>
<td>Cost/ft² (ft²)</td>
<td>Cost/ft² (ft²)</td>
<td>Cost/ft² (ft²)</td>
<td>Cost/ft² (ft²)</td>
</tr>
<tr>
<td>Pre-cast Concrete</td>
<td>$20.00 (16,700)</td>
<td>$18.28 (37,305)</td>
<td>$120.00* (242)</td>
<td>$16.75 (54,557)</td>
<td>N.A.</td>
</tr>
<tr>
<td>Concrete Masonry</td>
<td>$15.00 (7,559)</td>
<td>$32.00 (17,720)</td>
<td>$15.00 (34,375)</td>
<td>$14.30 (54,961)</td>
<td>$15.40 (89,209)</td>
</tr>
<tr>
<td>Wood</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
</tbody>
</table>

*The published value of $120/ft² appears to be in error, but could be related to a single small-scale project with detailed surface finishes.

For a brief example of life cycle cost analysis, a simple analysis for a concrete masonry noise barrier is presented below.

Table VI. Present Worth

<table>
<thead>
<tr>
<th>Work Item</th>
<th>Year</th>
<th>Cost ($)</th>
<th>Present Worth Factor</th>
<th>Present Worth ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>Year built</td>
<td>15.40</td>
<td>1.000</td>
<td>15.40</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+05 years</td>
<td>00.20</td>
<td>0.863</td>
<td>0.173</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+10</td>
<td>00.20</td>
<td>0.744</td>
<td>0.149</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+15</td>
<td>00.20</td>
<td>0.642</td>
<td>0.128</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+20</td>
<td>00.20</td>
<td>0.554</td>
<td>0.111</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+25</td>
<td>00.20</td>
<td>0.478</td>
<td>0.096</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+30</td>
<td>00.20</td>
<td>0.412</td>
<td>0.082</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+35</td>
<td>00.20</td>
<td>0.355</td>
<td>0.071</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+40</td>
<td>00.20</td>
<td>0.307</td>
<td>0.061</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+45</td>
<td>00.20</td>
<td>0.264</td>
<td>0.053</td>
</tr>
<tr>
<td>Maintenance</td>
<td>+50</td>
<td>00.20</td>
<td>0.228</td>
<td>0.046</td>
</tr>
<tr>
<td>Life Cycle Cost</td>
<td></td>
<td>16.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The present worth factor is calculated by the formula

\[ PW \text{ Factor} = \frac{1}{(1.03)^n} \]

Where: 1.03 is the net interest rate of 3% (decimal) added to 1.0
n is the number of years from the start of the analysis

**Assumptions:**

- **Life Expectancy:** 50 years
- **Concrete Masonry Initial Cost:** $15.40/ft²
- **Maintenance Required:** $0.20/ft² performed every 5 years
- **Interest Rate:** 6% per annum
- **Construction Escalation:** 3% per annum
- **Net Interest for Present Value:** 3% per annum

In summary, life cycle cost analysis is a method of comparing various alternate sound wall designs on a rational basis. However, because input data for analysis is often sparse or unavailable, the results are highly dependent on the assumptions and estimates made to fill in missing information.

### 4.3 Masonry Wall Costs

The final cost of a masonry sound barrier wall is influenced by a number of variables. Costs tabulated with each of the conceptual designs shown in Section 3 include labor and material costs for only the wall systems and foundations as shown in the accompanying Figures. When preparing a budget estimate for a sound barrier wall project, be sure to consider the following variables.

1. **Design fees** may add up to 15 percent to the listed wall costs. Design costs include fees for architectural and structural design. Do not forget to include money for consultants such as an acoustical engineer, geotechnical testing, surveying, civil engineering, jobsite testing, and construction inspection.

2. **General contractors** charge a fee to organize the project, provide site management, temporary utilities, traffic control and weather protection. They also handle hiring, overseeing, and paying subcontractors. General contractor fees usually range from 15 to 20 percent of the total project cost, including charges for their overhead and profit. Some mason contractors act as their own general contractor for smaller masonry wall projects, which can help to save money on the total project cost.

3. **Any existing fences or wall components** (such as brick columns) that are not easily integrated into new wall systems are usually demolished before beginning wall construction. Entry features...
may be retained, incorporating the old entry into the design of a new wall system.

4. Underground utilities such as water and sewer, electrical supply, cable television, and telephone service are often located along property lines near or beneath wall alignments. It is best to locate utilities as part of the preliminary design process, and design the wall and foundation to minimize conflicts with existing utilities. Special foundation systems may also be designed to bridge over utilities. Utility relocation is expensive and disruptive and should be avoided if possible.

5. Masonry walls are heavy and local authorities may require replacement of existing sewer lines with cast iron ones for any portion of the sewer that crosses under the wall. This precaution is not required if the foundation can bridge over existing utilities.

6. Landscaping costs will be dependent upon the basic wall design, foundation type, and the maturity of in-place trees and shrubbery. Mason crews need a clear space of at least 8 feet on the front side of the wall and about 3 feet on the back side of the wall for wall construction. Landscaping within this zone will have to be tied back, relocated, or removed. Underground irrigation lines and pop-up sprinkler heads are likely to be damaged if they are in close proximity to the wall alignment. If landscaping is extensive and mature, landscape damage and subsequent replacement costs can be reduced by using a prefabricated masonry wall that is built off-site and lifted into place. If the wall will pass close to the root system of mature trees, consider using a drilled pier foundation system. The drilled piers cause less damage to the existing tree roots, improving the tree’s chances for survival.

<table>
<thead>
<tr>
<th>Table VII. Additional Wall Cost Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Item</td>
</tr>
<tr>
<td>Design fees</td>
</tr>
<tr>
<td>General contractor</td>
</tr>
<tr>
<td>Demolition of existing fences</td>
</tr>
<tr>
<td>Utility relocation</td>
</tr>
<tr>
<td>Landscaping replacement costs</td>
</tr>
<tr>
<td>Minimal</td>
</tr>
<tr>
<td>Moderate</td>
</tr>
<tr>
<td>Mature</td>
</tr>
</tbody>
</table>
4.4 Cost multipliers for various cities

All of the costs discussed to this point are for masonry walls built in Denver, Colorado, using the value of the dollar in 2006. To apply these estimated costs to masonry construction in other regions of the country, consult a current cost estimating guide (such as the Means [6] reference). Use the multipliers listed in these guides to modify costs based on production rates, material costs, and labor rates for the area. Cost multipliers incorporating masonry labor, material, and production rates for some U.S. cities are listed in Table VIII.

Table VIII. Cost Multipliers for Selected U.S. Cities (adapted from Means [6])

<table>
<thead>
<tr>
<th>Location</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denver, Colorado</td>
<td>1.00</td>
</tr>
<tr>
<td>Los Angeles, California</td>
<td>1.13</td>
</tr>
<tr>
<td>Seattle, Washington</td>
<td>1.09</td>
</tr>
<tr>
<td>Phoenix, Arizona</td>
<td>0.92</td>
</tr>
<tr>
<td>Chicago, Illinois</td>
<td>1.17</td>
</tr>
<tr>
<td>St. Louis, Missouri</td>
<td>1.07</td>
</tr>
<tr>
<td>Houston, Texas</td>
<td>0.91</td>
</tr>
<tr>
<td>Baltimore, Maryland</td>
<td>0.95</td>
</tr>
<tr>
<td>Boston, Massachusetts</td>
<td>1.20</td>
</tr>
<tr>
<td>Raleigh/Durham, North Carolina</td>
<td>0.79</td>
</tr>
<tr>
<td>Miami, Florida</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Note: multiply costs listed in this publication by the multiplier listed for the selected city. See RSMeans annual cost estimating books to develop multipliers for other localities.

Note that in smaller cities not listed, the labor rates may be less than that of the nearest listed city but may be offset by increased material transportation costs.
4.5 Escalation

In general, construction costs tend to increase yearly. For masonry construction in the Denver area, escalation is currently compounded at 3.4 percent per year (Consumer Price Index, 1993 to 2003 according to the U.S. Department of Labor, Bureau of Labor Statistics). Escalation rates will vary, however, depending on the area of the country and the local construction environment. Consult current cost estimating manuals for escalation rates in the area.

Table IX. Multiplier for cost escalation is dependent on average inflation rate and number of years elapsed since base year

<table>
<thead>
<tr>
<th>Number of Years</th>
<th>Average Inflation per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1%</td>
</tr>
<tr>
<td>1</td>
<td>1.01</td>
</tr>
<tr>
<td>2</td>
<td>1.02</td>
</tr>
<tr>
<td>3</td>
<td>1.03</td>
</tr>
<tr>
<td>4</td>
<td>1.04</td>
</tr>
<tr>
<td>5</td>
<td>1.05</td>
</tr>
<tr>
<td>6</td>
<td>1.06</td>
</tr>
<tr>
<td>7</td>
<td>1.07</td>
</tr>
<tr>
<td>8</td>
<td>1.08</td>
</tr>
<tr>
<td>9</td>
<td>1.09</td>
</tr>
<tr>
<td>10</td>
<td>1.10</td>
</tr>
</tbody>
</table>

Note: Interpolation between listed inflation rates by adding 1.0 to the inflation rate (divided by 100) and using the number of years as an exponent. For example, to determine the cost escalation factor for 3.5% inflation rate over 7 years: cost factor = \((1.035)^7 = 1.27\).
4.6 Wall Cost Example

The following example illustrates how to calculate an approximate cost of a masonry wall. For this example, a pier and panel wall built using modular brick is assumed. See the various Conceptual Designs for an example of this wall type. The wall to be priced is 8-feet-tall and spans 18-feet between piers. A modular brick soldier course is added as an additional feature near the top of the wall.

For a wall being constructed in an existing neighborhood, costs for existing conditions must be considered. For this example it is assumed that the masonry sound wall is being constructed to replace an existing wood fence. This will require demolition and removal. It is also assumed that there are utilities and moderate landscaping that needs to be relocated or replaced. Additionally, the wall will not have a setback from the sidewalk, requiring traffic control along the existing roadways while construction is being conducted in these areas.

The costs associated with this masonry wall are as follows:

**Table X. Wall Costs**

<table>
<thead>
<tr>
<th>Wall Features</th>
<th>Cost per linear foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modular Brick Wall (8-ft tall)</td>
<td>$172.78</td>
</tr>
<tr>
<td>Modular Brick Soldier Course</td>
<td>$14.35</td>
</tr>
<tr>
<td><strong>Wall Features Subtotal =</strong></td>
<td><strong>$187.13</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional Site Work</th>
<th>Cost per linear foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demolition of Existing Fences</td>
<td>$5.00</td>
</tr>
<tr>
<td>Utility Relocation</td>
<td>$10.00</td>
</tr>
<tr>
<td>Traffic Control</td>
<td>$15.00</td>
</tr>
<tr>
<td>Landscape Replacement</td>
<td>$50.00</td>
</tr>
<tr>
<td><strong>Additional Site Work Subtotal =</strong></td>
<td><strong>$80.00</strong></td>
</tr>
</tbody>
</table>

**Wall Cost Subtotal = $267.13**

<table>
<thead>
<tr>
<th>Design &amp; Construction</th>
<th>Cost per linear foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Design Fees</td>
<td>$18.71</td>
</tr>
<tr>
<td>General Contractor Fees</td>
<td>$40.07</td>
</tr>
<tr>
<td><strong>Design &amp; Construction Subtotal =</strong></td>
<td><strong>$58.78</strong></td>
</tr>
</tbody>
</table>

**Grand Total = $325.91**

It is important to note that for a wall with an initial basic wall cost of $172.78 per linear foot, the final cost is nearly twice that at $325.91 per linear foot.
5. Resources


Appendix

Local, State and Regional Masonry Associations

Rocky Mountain Masonry Institute
686 Mariposa Street
Denver, Colorado 80204
Phone 303-893-3838
Fax 303-893-3839
Email: admin@rmmi.org

Brick SouthEast
8420 University Executive Park Drive, Suite 800
Charlotte, North Carolina 28262–3381
704.510.1500
Fax 704.510.0042
OR
1810 Overlake Drive, Suite A
Conyers, Georgia 30013–1787
770.760.0728
Fax 770.760.7810
www.gobricksoutheast.com

Brick Institute of America, Mid East Region
Box 35575
Canton, Ohio 44735–5575
330.492.0303
Fax 330.492.7373

Heartland Brick Council
5665 Greendale Road
Johnston, Iowa 50131–1508
877.202.5554
Fax 515.252.0645
www.heartlandbrick.org

Masonry Advisory Council
1480 Renaissance Drive, Suite 302
Park Ridge, Illinois 60068
847.297.6704
Fax 847.297.8373
www.maconline.org

Southwestern Brick Institute
3000 South 31st Street, Suite 507
Temple, Texas 76502
800.733.8213
Fax 254.771.2011
www.swbrick.com

Western States Clay Products Association
22815 Frampton Avenue
Torrance, CA 90501
310.257.9000
Fax 310.257.1942
www.wscpa.us
Regional Masonry Associations
Arizona Masonry Guild (Phoenix, AZ) www.masonryforlife.com
Carolinas Concrete Masonry Association (Greensboro, NC) www.ccmaonline.com
Masonry Institute of America (Torrance, CA) www.masonryinstitute.org
Masonry Institute of Washington (Seattle, WA) www.masonryinstitute.com

National and Masonry-related Associations
Brick Industry Association www.gobrick.com
Mason Contractors Association of America www.masoncontractors.com
The Masonry Society www.masonrysociety.org
National Concrete Masonry Association www.ncma.org
Portland Cement Association www.portcement.org
MasonryDetails.com www.masonrydetails.com
Residential Masonry Contractors Association www.residentialmasonrycontractors.com
American Concrete Institute www.aci-int.org
American Concrete Pavement Association www.pavement.com
American Concrete Pipe Association www.concrete-pipe.org
Architectural Engineering Institute of ASCE www.aeinsitute.org
Association of Equipment Manufacturers www.aem.org
American Institute of Architects www.aia.org
Associated Landscape Contractors of America www.alca.org
American National Standards Institute www.ansi.org
American Portland Cement Alliance apca
American Society of Concrete Contractors www.ascconline.org
American Society of Civil Engineers www.asce.org
American Society of Landscape Architects www.asla.org
ASTM International www.astm.org
Photo Credits

Cover photo  *Michael Schuller, Atkinson-Noland*

P. 7 Minnesota Sound Wall *Olene Bigelow, International Masonry Institute.*

P. 8 Arizona Masonry Fence *Michael Schuller, Atkinson-Noland*

P. 9 North Carolina Sound Wall Photos courtesy of Brick Southeast, photography by Roger Ball

Photography

P. 10 California Sound Wall *Thomas Escobar, Masonry Institute of America*

P. 10 Split-face Sound Wall *Michael Schuller, Atkinson-Noland*

P. 11 Greenwood Village Masonry Fence *Atkinson-Noland*

P. 12 Texas Thinwall Fence, *Hoggatt LP*

P. 12 Texas Thinwall Fence *Hoggatt LP*

P. 14 Split-face Concrete Block *Rocky Mountain Masonry Institute*

P. 15 Pier Wall Height Change *Atkinson-Noland*

P. 16 Cantilever Wall Height Change *Atkinson-Noland*

P. 16 Landscaping *Atkinson-Noland*

P. 17 Control Joints *Rocky Mountain Masonry Institute*

P. 18 Brick Expansion Joint *Atkinson-Noland*

P. 22 Cantilever Wall *Thomas Escobar, Masonry Institute of America*

P. 24 Pier and Panel *Atkinson-Noland*

P. 26 Prestress rods *Atkinson-Noland*

P. 35 California Sound Wall *Thomas Escobar, Masonry Institute of America*

P. 39 Prestress Sleves *Atkinson-Noland*

P. 39 Metal Plates *Atkinson-Noland*

P. 41 Suspended Wall on Caissons *Rocky Mountain Masonry Institute*

P. 71 Subdivision Entrance *Rocky Mountain Masonry Institute*

P. 73 Cracked Joint *Rocky Mountain Masonry Institute*

Back cover *Rocky Mountain Masonry Institute*
Tables and Figures

Tables

P. 28 Table I. Sound Reduction Feasibility (adapted from AASHTO, Guide on Evaluation and Attenuation of Traffic Noise)


P. 76 Table III Representative Costs (Atkinson–Noland)

P. 77 Table IV Architectural Costs (Atkinson–Noland)

P. 80 Table V Cost Data (Cost data and quantity constructed by year for noise barriers from Colorado Department of Transportation’s Cost Data Books.)

P. 80 Table VI Present Worth (Atkinson–Noland)

P. 82 Table VII Additional Costs (Cost Multipliers for Selected U.S. Cities (adapted from Means [6]))

P. 83 Table VIII. Cost Multipliers for Selected U.S. Cities (adapted from RS Means [6])

P. 84 Table IX Annual Cost Multiplier (Atkinson–Noland)

P. 85 Table X Wall Cost Example (Atkinson–Noland)

Figures

P. 21 Fig. a. Sound Paths (Atkinson–Noland)

P. 21 Fig. b. Diffracted Sound Paths (Atkinson–Noland)

P. 29 Fig. c. Noise Barrier Length (Michael Schuller, Atkinson–Noland)

P. 30 Fig. d. Sound Path length (Michael Schuller, Atkinson–Noland)

P. 36 Fig. e. Cantilever Wall Design (Michael Schuller, Atkinson–Noland)

P. 38 Fig. f. Pier and Panel Wall Design (Michael Schuller, Atkinson–Noland)

P. 42 Fig. g. Cantilevered Pier Cap (Michael Schuller, Atkinson–Noland)

P. 42 Fig. h. Bridge Pier Cap (Michael Schuller, Atkinson–Noland)

P. 71 Fig i. Detailing (Diane Travis, Rocky Mountain Masonry Institute)

P. 72 Fig. j. Control Joint Detail (Michael Schuller, Atkinson–Noland)

P. 73 Fig. k. Concrete Block Control Joints (Michael Schuller, Atkinson–Noland)