CONCRETE MASONRY SOUND WALLS

C. Thompson[1], S. Ganzerli[2], and T. Young[3]

[1] Undergraduate Research Assistant, Department of Civil Engineering, School of Engineering and Applied Science, Gonzaga University, Spokane, WA, 99258, USA, cthompson6@zagmail.gonzaga.edu

[2] Professor, Department of Civil Engineering, School of Engineering and Applied Science, Gonzaga University, Spokane, WA, 99258, USA, ganzerli@gonzaga.edu

[3] Executive Director, Northwest Concrete Masonry Association, 16300 Mill Creek Blvd, #208-C, Mill Creek, WA, 98012, USA, tcyoung@nwcma.org

ABSTRACT

This study explores the use of concrete masonry walls employed as sound barriers for highway noise reduction. Concrete masonry is a widely used material in construction but its ability to effectively work as a sound barrier is understated. Successful application of concrete masonry sound walls can be found in California where these kinds of barriers have recently grown in popularity. Other examples of their application are illustrated in the segment from Spokane to Seattle of I-90 in Washington State. Investigations on the effectiveness of concrete masonry sound walls have been conducted by several agencies including: The National Concrete Masonry Association (NCMA), The Northwest Concrete Masonry Association (NWCMA), The Masonry Society (TMS), the Federal Highway Administration (FHWA), and The Institute for Research in Construction (IRC). Concrete masonry walls provide excellent Sound Transmission Loss (STL) due to their high material density. In addition to this they absorb and diffract sound waves. Concrete masonry walls are economically efficient for construction because of their durability and low cost maintenance. They also offer a plethora of attractive aesthetic solutions. This paper presents an overview of the information currently available on concrete masonry unit (CMU) highway sound barriers. It outlines the versatility of their application and delineates the opportunity for further studies on the subject. This manuscript is of interest for structural, transportation, civil, and environmental engineers. It summarizes the advantages that CMU sound walls present in mitigating the impact of highway construction and sound pollution on the environment.

KEYWORDS: sound attenuation, concrete masonry unit, noise pollution, sound transmission, noise control

INTRODUCTION

Sound walls (Fig. 1) are an increasingly popular sight along highways and freeways in the United States. According to the Federal Highway Administration (FHWA) the first noise barrier was constructed in 1963 [1]. From 1963 until the end of 2010 a total of 47 State Department of Transportations (SDOTs) have spent $4.05 billion ($5.44 billion in 2010 dollars) on 2,748 linear miles of noise barriers throughout the United States [2]. Various materials are considered in the studies conducted by the FHWA including concrete masonry units, wood, metal, earth berms, brick, and hybrid systems. It is also worth noting that precast/cast-in-place concrete and CMUs are used more frequently. 53.31% of barriers constructed between 1963 and 2010 were designed with precast/cast-in-place concrete and 21.48% were designed with CMU systems [2].

Figure 1: Mortarless CMU sound wall (courtesy of NWCMA)

The Northwest Concrete Masonry Association (NWCMA) has published a brochure that highlights the benefits of concrete masonry sound walls. In this brochure they state that, as traffic levels increase across the nation, many residential areas are experiencing unwanted sound pollution levels [3]. To address this problem barriers are used to limit the transmission of sound reaching residential areas. While there are other strategies to control noise pollution, including motor vehicle regulation, roadway construction planning, and land use, the most efficient methods of sound control are walls constructed with dense concrete material (Fig. 2). The density and stiffness of these walls enable an optimal sound absorbing and reflecting performance. The NWCMA also states that properly constructed sound barriers can halve the perceived noise level from transportation sources [3]. As sound levels are reduced the quality of life for residents in noise polluted environments increases. Citizens claim to sleep better, hold easier conversations, and feel more satisfied with their living environment [3].

Mr. Jason Thompson, Vice President of Engineering at the National Concrete Masonry Association, mentioned the lack of focus on sound attenuation in sound barriers over the past few years [4]. In addition to this, the majority of research focused on concrete masonry walls has been conducted using sound frequencies that compare to inside noise sources like the human voice. The data representing the effectiveness of these types of walls subject to transportation sound sources like airports, freeways, and railroads is scarce. While the available data may show that the density and stiffness of CMUs provide adequate Sound Transmission Loss, there is a general need for more technical knowledge of the performance of these materials subject to specific transportation noise sources.

Figure 2: Textured CMU wall, Highway 101 San Francisco (courtesy of NWCMA)

SOUND TRANSMISSION

In understanding the performance of sound walls it is important to be aware of how sound behaves. Sound transmission involves the movement of sound waves through the air (or other medium) as particles transfer energy from one to the other [5]. Hence, the goal of a sound barrier is to reduce the sound transmission and produce sound attenuation (loss).

Sound attenuation can be obtained by reflection, diffraction, and absorption. Reflection occurs when sound waves come into contact with an object, such as a wall, and reverse direction. Similar to reflection, diffraction is an important aspect of sound behaviour. Diffraction involves the bending of sound around objects. When diffraction occurs sound waves travel over the top of a sound wall and bend toward the ground on the opposite side. This makes the height of walls a significant factor in blocking sound. Absorption occurs when sound energy is released as heat energy. High density materials like concrete are able to do this well because of their rigidity and density.

The following describes the scales available to measure sound. Sound intensity is measured with units of decibels (dB). High decibel ratings on the range of 110-150 dB result from sources like jet aircraft, thunder, and rock bands. Smaller decibel levels on the range of 3-20 dB are equivalent to someone whispering or breathing normally [6]. There is another measure of noise intensity scaled to reflect how humans perceive sound called “A-weighted levels”. This measurement is calculated in units of dB(A). On this scale an increase of 10 dB(A) would double the sound intensity that humans hear [3]. Frequency, or the number of wavelengths that pass a certain point each second, is responsible for determining the sound pitch, and is measured in hertz (Hz). Normal human perception ranges from 16-20000 Hz. It should also be noted that materials have natural frequencies and will transmit sound much easier if the sound interacting with the material is of the same frequency. When this occurs, the medium will vibrate in harmony with the sound waves, transmitting sound energy through the medium at high efficiency. In design, it is important to avoid using materials that are sensitive to the frequency of sound that the wall will experience [6].

SOUND TRANSMISSION LOSS AND SOUND TRANSMISSION CLASS

The Sound Transmission Class (STC) is an important property of wall systems that is used to classify how effective a wall is in reducing sound transmission. The STC is determined via ASTM E 90, the *Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements* and ASTM E 413, the *Classification for Rating Sound Insulation* [7, 8]. In order to determine the STC rating, Sound Transmission Loss (STL) data is measured over a range of frequencies. STL values are determined by measuring the reduction in sound intensity that given wall designs produce at specific sound frequencies. The NCMA states that heavier concrete masonry units have higher associated STC ratings [6]. In addition, The Masonry Society (TMS) has provided an equation (see Eq. 1) for determining the STC rating of concrete masonry walls based on weight per unit area W kg/m^2. This equation applies to walls that are 75 mm (3 inches) or greater in thickness [9].

$$STC = 14.1W^{0.234} \tag{1}$$

A study by the Institute for Research in Construction (IRC) also determined that for walls with no surface finish sound loss increased by 5dB for every time the wall weight per unit area doubles [10]. It has also been shown that by adding sound absorbing material to wall cavities and block sealer on the outside faces STC ratings are further improved [11]. The block sealer improves transmission loss by sealing pores, gaps, or holes that may allow sound to transmit through the wall structure. Sound absorbing material is also beneficial because it reduces sound energy that transmits inside of wall cavities. The STC rating of a wall is determined using a wide range of sound frequencies. Because of this, it is harder to gauge the performance of a sound wall subject to specific transportation sound frequencies with the STC value. Therefore, STC values determined through ASTM E 90 and E 413 may not accurately represent the performance of a highway sound barrier under specific sound conditions [12]. A more accurate representation of sound attenuation for outside noise pollution is the Outdoor-Indoor Transmission Class.

OUTDOOR-INDOOR TRANSMISSION CLASS

The Outdoor-Indoor Transmission Class (OITC) is very similar to the STC reviewed above. The OITC is determined by ASTM Standard E 1332 the *Standard Classification for Determination of Outdoor-Indoor Transmission Class* [13]. The NCMA states that this transmission class is based on sound attenuation from aircraft, freeway, and railroad type sound sources [14]. Furthermore, it is a measure of how well sound walls protect indoor environments from outdoor sound pollution. TMS has also provided an equation (see Eq. 2) for determining the OITC of concrete masonry walls with a thickness greater than 75 mm (3 inches) based on wall weight per unit area W kg/m^2 [9]. Compared to the STC this may be a better factor to consider when designing sound walls next to freeways and transportation systems because of the difference in frequencies used during experimentation.

$$OITC = 9.28W^{0.290} \quad (2)$$

SOUND WALL TYPES AND PERFORMANCE

There are a variety of sound wall designs commonly used. This section addresses their sound performance compared to concrete masonry units. CMU systems are frequently employed because of the efficient nature of their sound blocking abilities. Below is a compilation of data showing different STL, STC, and OITC values for concrete masonry and comparable materials.

A study conducted by the IRC examined the following specimens [15]:

- 140 mm (6 inch) thick normal weight concrete masonry units with average weight per block of 15.9 kg (35 lb)
- 190 mm (8 inch) acoustical units with average weight per block of 17.8 kg (39.25 lb)
- 240 mm (10 inch) normal weight concrete masonry units with average weight per block of 21.3 kg (47 lb)

The 190 mm (8 inch) acoustical units used in testing are noteworthy because they feature two acoustical slots on each face and three coats of latex block sealer applied to the non-slotted face for extra sound absorption. The STC values calculated for the concrete masonry units are the following:

- 45 for the 140 mm (6 inch) CMUs
- 52 for the 190 mm (8 inch) acoustical CMUs
- 48 for the 240 mm (10 inch) CMUs

In this testing the acoustical concrete units have the highest STC value because the slotted face feature and block sealant improved sound absorption and reflection. However, the author of this study pointed out that the addition of the block sealant alone increased the STC value from 46 to 52. This study shows that surface finishes can significantly improve sound blocking abilities, while acoustical slots may not greatly affect sound loss. Sound attenuation is improved with the addition of block sealant, but the long term cost versus benefit must be considered. The application and maintenance of block sealer may not be favourable to construction time and budget restrictions. It may be more practical to use a thicker CMU rather than applying sealant. In this way, construction time and costs are reduced without sacrificing sound blocking performance. It is also worth noting the effect that weight and thickness have on STC values. This relationship is highlighted when comparing the heavier and thicker 240 mm (10 inch) CMU with the smaller and lighter 140 mm (6 inch) CMU. The former has a STC value that is 3 dB greater than the latter. In conclusion, this study is significant because it displays how block sealer, acoustical slots, thickness, and weight affect sound attenuation. It also shows that conventional (without acoustical requirements) concrete masonry units perform well in sound attenuation.

As stated before, the OITC rating system may be a better judge of the performance of highway sound barriers. OITC ratings for various wall thickness and weight have also been published by the NCMA [14]. These ratings apply to single wythe concrete masonry walls. The data is as follows:

- 90 mm (4 inch) thick walls with a wall weight of 1 kN/m^2 (20.7 lb/ft^2) have an OITC rating of 32
- 140 mm (6 inch) thick walls with a wall weight of 1.2 kN/m^2 (25.1 lb/ft^2) have an OITC rating of 37
- 190 mm (8 inch) thick walls with a wall weight of 1.7 kN/m^2 (36.2 lb/ft^2) have an OITC rating of 39

These ratings show that OITC values, similar to STC values, also increase as thickness and wall weight increase.

Another study published in NCMA's Concrete Masonry Design magazine compares wood, metal, masonry, and concrete sound wall systems [16]. This paper allows comparisons to be made between the effectiveness of concrete masonry and competing materials. The wood fence designs considered in this article provide a Sound Transmission Loss between 15-23 dB. The metal designs (aluminum and steel) showed losses between 15-27 dB. Higher transmission loss values, between 36-40 dB, were recorded for the cast-in-place concrete walls. Similar loss values were also shown for concrete masonry structures, displaying between 7-40 dB of sound loss. This data displays how less dense material, like wood and aluminium, has trouble stopping the transmission of sound. The unit weight, density, and stiffness of concrete masonry allows for greater sound attenuation.

The FHWA has conducted a study of common noise barrier materials and their associated Sound Transmission Loss values. The wall systems in consideration have been constructed with a single material, have no gaps or holes in the wall design, and are tested by A-weighted highway traffic frequency spectra [1]. Here are the findings:

- 200 mm (8 inch) lightweight concrete block wall has a STL of 34 dB(A)
- 150 mm (6 inch) light concrete wall has a STL of 39 dB(A)
- 18 ga steel wall with thickness 1.27 mm (0.050 inch) has a STL of 25 dB(A)
- 6.35 mm (0.25 inch) thick aluminum sheet has a STL of 27 dB(A)
- 50 mm (2 inch) thick wood (fir) wall has a STL of 24 dB(A)
- 25 mm (1 inch) thick plywood wall has a STL of 23 dB(A)
- 3.18 mm (0.125 inch) thick safety glass wall has a STL of 22 dB(A)
- 6 mm (0.25 inch) thick plexiglas wall has a STL of 22 dB(A)

This data shows how well each wall type performs. Again, it is apparent that the concrete masonry units provide one of the best protections against sound pollution.

FURTHER DISCUSSION ON CMU TRAFFIC SOUND BARRIERS

As previously stated in this document, a review of published literature shows that concrete masonry is an effective sound blocking material. Other remarkable advantages can also be found in using concrete masonry walls for traffic noise attenuation. Concrete masonry is significantly more economical with respect to other materials. Research from the FHWA shows that over the last ten years the average cost of wall systems, including all material types, is $30.56 per square foot [2]. In a telephone interview, Mr. Adrian Siverson, Project Manager at R&D Masonry, Inc., indicated that the average cost of constructing a mortarless concrete masonry sound wall is $10-15 per square foot [17]. This refers to the finished product and includes all other materials used in the wall construction and placement. It can be inferred that CMU sound walls are economically advantageous with respect to other constructions employed during the last ten years. In addition, Mr. Siverson stated that CMU walls are easy to build and do not require as much cleanup as other construction materials. Using concrete masonry saves money by reducing construction time. CMU walls are also virtually maintenance free as they are known to be long lasting construction without the need to be repaired or modified. The NWCMA has highlighted that masonry block systems allow planners and engineers a wide range of design options because of the unit by unit construction process. This permits engineers to combine functionality with aesthetics (Fig. 3).

Figure 3: Construction of a CMU wall (courtesy of R&D Masonry, Inc.)

FUTURE STUDIES

This paper is the first step towards addressing future studies focusing on experimentation with concrete masonry sound walls subject to transportation sound sources. It helps identify the dependence of sound transmission primarily from thickness and weight per unit area. It would be beneficial to analyse how these wall designs behave subject to specific sound frequencies emitted by highways, railroads, and airports. These studies would include non-destructive laboratory testing on a variety of common concrete masonry walls in order to determine STL, STC, or OITC ratings.

CONCLUSIONS

It can be concluded that concrete masonry sound walls are an efficient way of controlling sound pollution because of their high STC, OITC, and STL values. They are able to absorb, reflect, and diffract sound energy effectively. The most important factors considered when designing sound walls for performance are the weight per unit area, thickness, and density of the masonry units. CMUs also offer relatively low construction costs in the short term and low cost long term maintenance because of their durability and strength. In addition, CMUs allow for attractive architectural solutions to noise pollution. Concrete masonry is simple, yet effective for highway sound insulation. There is, however, a general lack of data surrounding the performance of masonry wall systems encountering transportation noise sources. It would benefit the engineers and planners who seek to design concrete masonry walls if more technical information was available. This paper sets the foundation for future studies to incorporate more testing of concrete masonry wall systems, specifically in the transportation environment.

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