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Verification of Scale Model and Full Model for Sound Barrier Along the Highway by FEA

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Abstract: The purpose of this research is to validate scale and full-size models for the deployment of a sound barrier along roadways. The aim is to find insertion loss that produce by scale and full size that simulate by using ANSYS Workbench Software. The study incorporates sound measurements, computational modelling, and analysis techniques to compare the sound pressure level before and after the installation of the barrier. The research utilises both the scale model and the full-scale model. This research allows for cost-effectiveness and efficiency. The trend of the graph is quite different. However, the insertion loss differences for simulation and experiment are not far apart. The maximum difference is 6.01 dBA, and the minimum difference is 0.08 dBA. This study's outcomes will help design effective and optimised sound barriers, reducing noise pollution and improving the general quality of life near roads.

Keywords: ANSYS Workbench Software, Insertion Loss, Computational Modelling, Scale Model, Full-Size Model.

1. Introduction

The purpose of highway noise barriers is to lessen the impact of traffic noise along the roadway. Noise barriers usually obstruct the direct flow of sound from the roadway source to the exposed receiver. Highway noise barriers, which are typically built using concrete, wood, metal, or plastic for walls and earth for berms, are becoming more commonly used to reduce highway noise.

Insertion loss is used to determine the noise barrier's effectiveness. Insertion loss is defined as differences between the measured sound pressure levels behind existing barriers and without barriers[1]. In other words, such a measurement gives a clear indicator of the improvement brought about by placing an attenuating building component between the noise source and the listener.

A scale model is a physical representation of a geometrically equivalent item (known as the prototype). Scale models may be bigger than small prototypes such as anatomical structures or

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subatomic particles, but they are often smaller than huge prototypes such as automobiles, buildings, or people. In addition to being used as toys, scale models are also utilised as tools for engineering design and testing, marketing, and sales, as well as for military strategy and special effects in movies.

Traffic noise is getting more attention lately because of the rapid growth of motorways. This noise is becoming a problem for people living near highways, as it interrupts their daily lives. To solve this, noise barriers made of metal, earth, or concrete are commonly used to reduce traffic noise and protect nearby homes from the noise. However, more research and experimentation are needed to build effective and affordable noise barriers. In Malaysia, research on noise barriers is limited because conducting experiments on highways is difficult and expensive. Instead, conducting studies on scale models is easier, cheaper, and saves time and energy.

This study work embarks to identify insertion loss of scale model and full-size model sound barrier by simulation then validate the result. The simulation was carried out in ANSYS with Harmonic Acoustic Analysis.

2. Materials and Methods

In order to ensure that a research study is completed correctly and that it proceeds without any problems, methodology is utilised. The study starts by finding information related to highway barriers and their dimensions by doing a review through previous studies, journals, books, and sources from the internet.

2.1 Geometrical modelling

The model follows the plan and cross section of Madrid Highway. Figure 1 and Figure 2 shows cross section for metal and berm wall in "Los Madronos" Hospital and in residential area on periphery of Madrid [2].

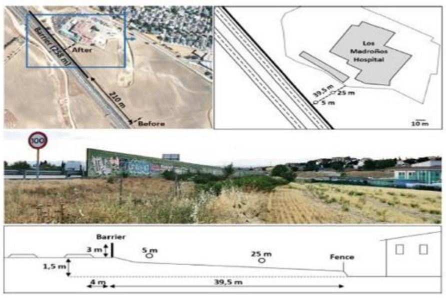

Figure 1: Plan and cross section for metal wall [2]

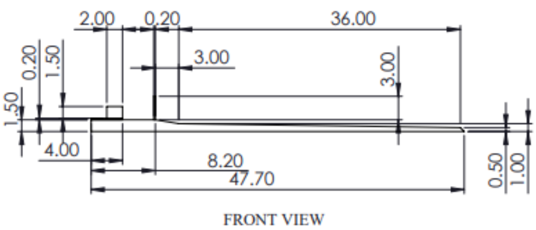

Figure 2: Geometry drawing for wall

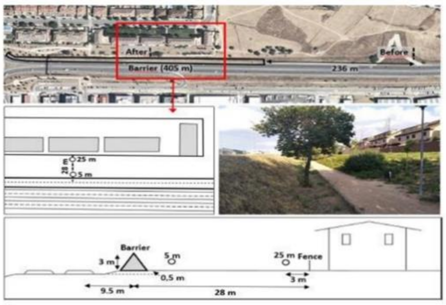

Figure 3: Plan and cross section for berm wall [2]

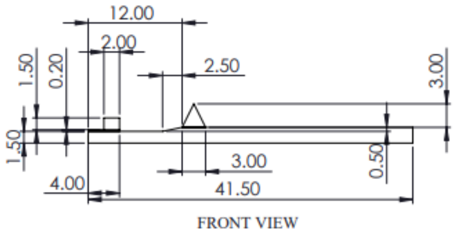

Figure 4: Geometry drawing for berm wall

2.2 Methods

The ANSYS platform was utilised for the acoustic analysis. The analysis focused on a harmonic examination to determine the insertion loss before and after the noise barrier installation. The acoustic aspect was defined as air, and the noise source was represented by a sound wave excitation originating from a modelled car with a sound intensity of 100 dB. The sound receiver is positioned 5 meters and 25 meters away from the noise barrier. The noise barrier is modelled as a 3-meter-high for both metal and berm. Parametric studies were carried out to explore sound pressure levels at 5 meters and 25 meters from the noise barrier with different frequencies.

The acoustic medium encompassing the noise barrier and sound source was established as a domain to simulate the propagation of acoustic waves. Additionally, a radiation boundary has been set at the acoustic medium's surface to avoid the waves' reflection. It represented the presence of an acoustic medium extending infinitely far beyond the boundaries of the noise barrier model. Sound Absorption coefficient has been set at asphalt and soil surface.

The analysis was conducted between the frequency range of 31 Hz to 500 Hz for the full-size model and 310 Hz to 5000 Hz for the 1/10 scale model, considering the sound pressure level (SPL) to encompass a wide range of traffic noise. The calculation of sound pressure levels within the computational domain then represented the sound pressure level provided by a specific distance from the noise barriers. To measure and compare the insertion loss of each distance form noise barrier, two sound receivers were positioned at back of the barrier.

Insertion loss can be determined by using the equation [3]:

$$IL = L_p - L_{Pwb} \quad \text{Eq. 1}$$

Where:

IL = Insertion loss

L_p = Sound pressure level without barrier

L_{Pwb} = Sound pressure with barrier

2.3 Meshing determination

To get accurate results, there are formulas to find the minimum element size for specific frequencies at sound sources. The minimum size of element needed can be determined by using the equation below[4]:

$$E_t = \frac{c}{6 \times f} \quad \text{Eq. 2}$$

Where:

E_t = minimum element size

c = speed of sound

f = frequency

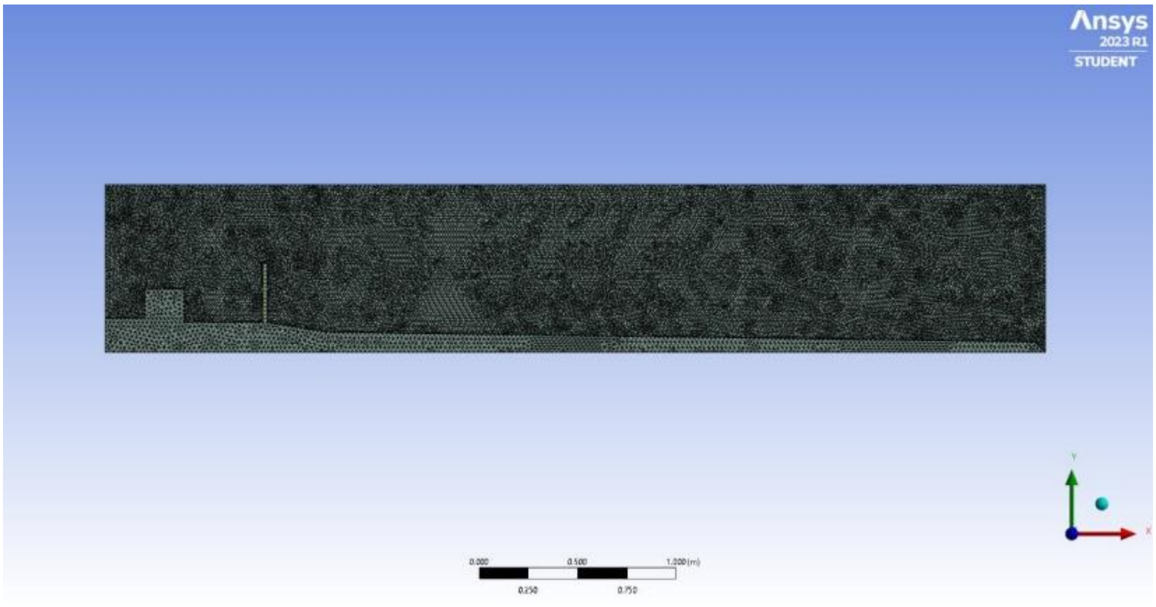

Figure 5: Meshing 1

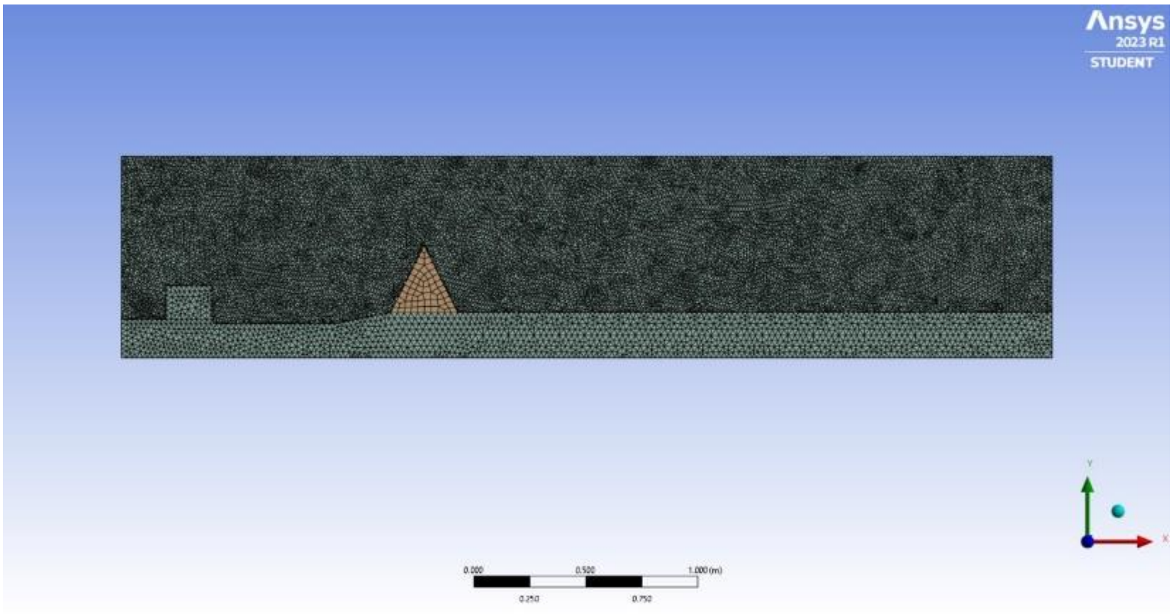

Figure 6: Meshing 2

Figure 5 and Figure 6 show meshing. Body sizing has been used in the meshing method.

3. Results and Discussion

3.1 Results

Figure 7 and Figure 8 represent the sound pressure distribution for a full-size metal wall and a full-size berm wall. The greatest sound pressure level was measured close to the source, which is around 100 dBA. The results revealed that as the distance from the sound source rose, the sound pressure dropped suddenly as it went over the noise barrier.

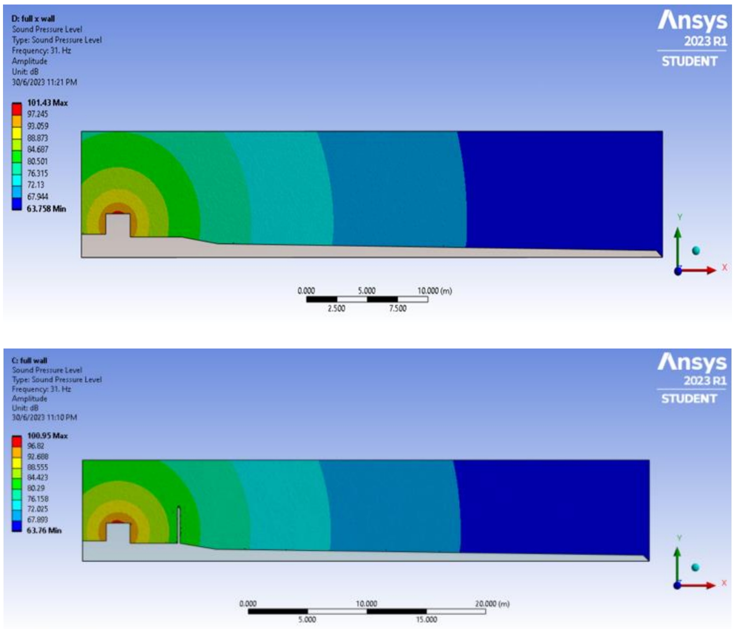

Figure 7: Sound Pressure Distribution for Full-size wall

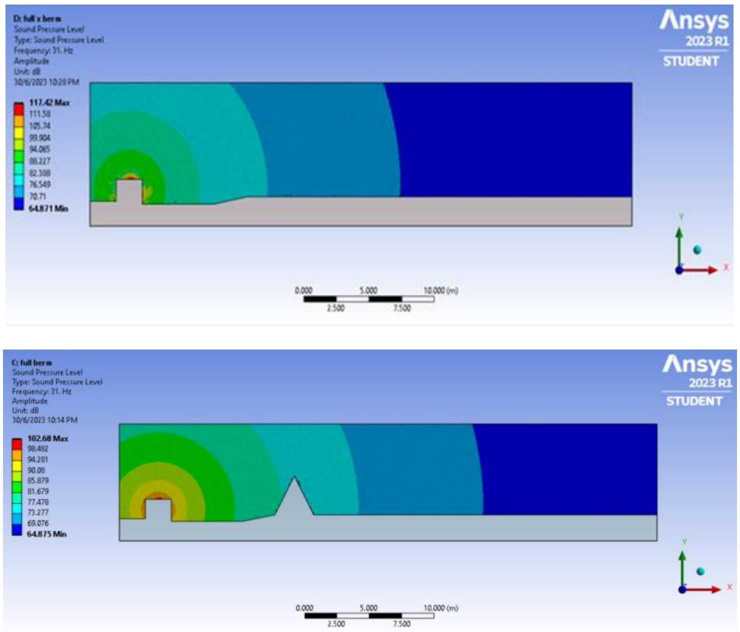

Figure 8: Sound Pressure Distribution for Full-size Berm Wall

Figure 9 and Figure 10 Show graph insertion loss against frequency for the full-size model. The insertion loss was calculated after the sound pressure level at 5 meters and 25 meters from the back of the barrier was defined. The calculation can be done by using equation (2.1). From the graph, the insertion loss at 5 meters is greater than 25 meters.

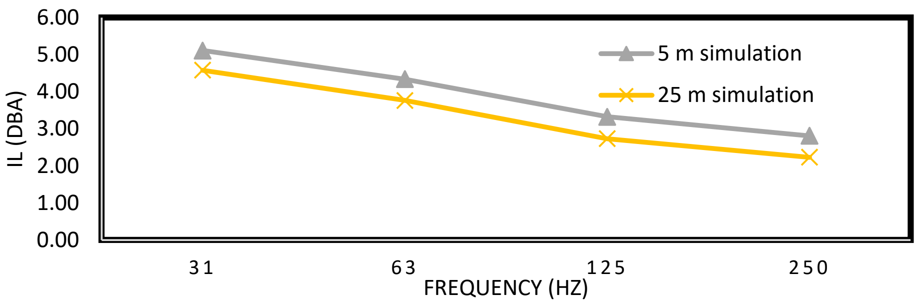

Figure 9: Result for full model metal wall

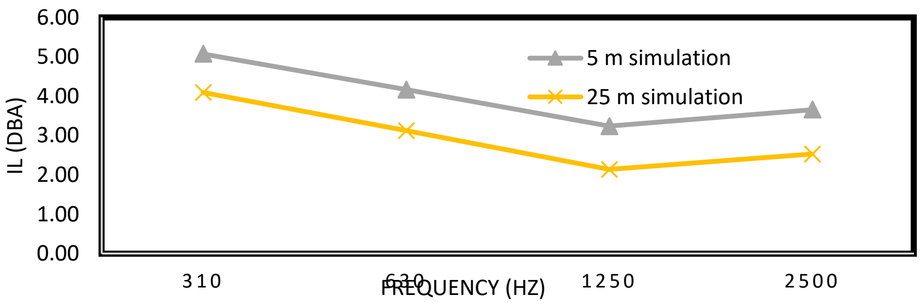

Figure 10: Result for full model berm wall

Figure 11 and Figure 12 represented the sound pressure distribution for a 1/10 scale model metal wall and scale model berm wall. The greatest sound pressure level was measured close to the source, which is around 100 dBA. The results revealed that as the distance from the sound source rose, the sound pressure dropped suddenly as it went over the noise barrier.

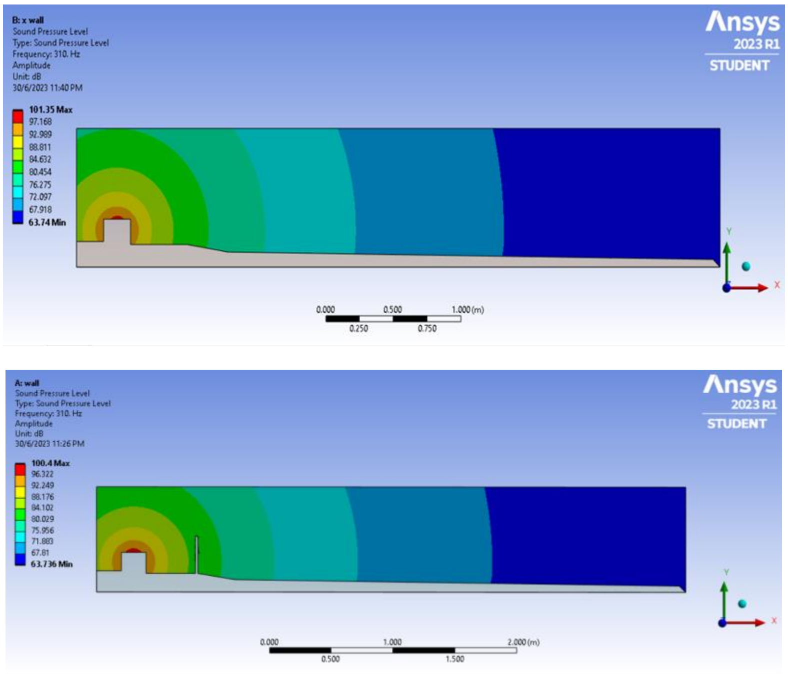

Figure 11: Sound pressure distribution for a 1/10 scale model metal wall

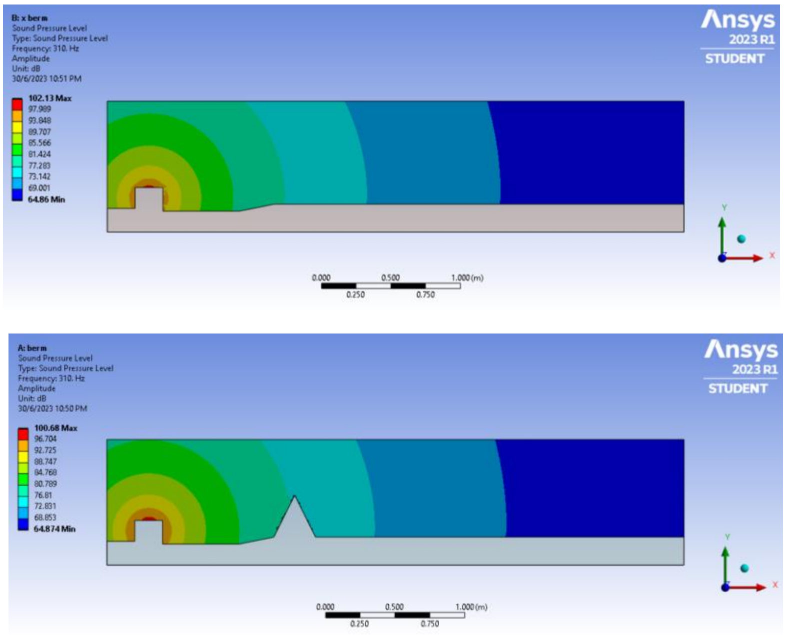

Figure 12: Sound pressure distribution for scale model berm wall

Figure 13 and Figure 14 Show graph insertion loss against frequency for 1/10 scale model. The insertion loss was calculated after sound pressure level at 5 meters and 25 meters from back of the barrier was defined. The calculation can be done by using equation 1. From the graph, the insertion loss at 5 meters is greater than 25 meters.

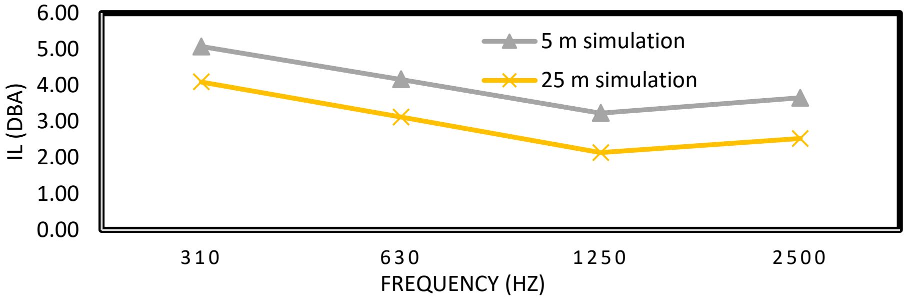

Figure 13: Result for 1/10 scale model metal wall

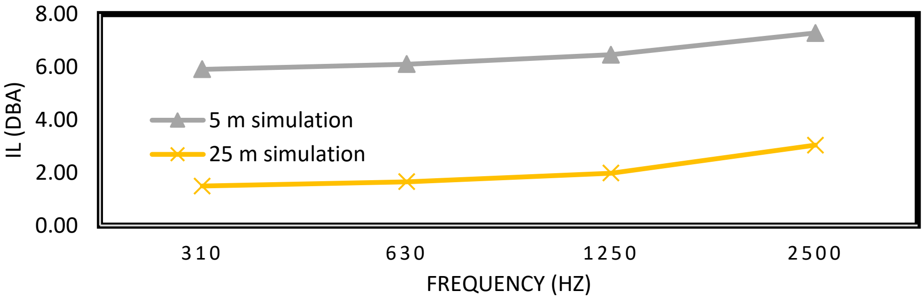

Figure 14: Result for 1/10 scale model berm

3.2 Discussions

The sound absorption coefficients at low frequencies increase as the sound pressure level rises, while high-frequency sound absorption coefficients are unaffected by high sound pressure levels. However, the sound absorption coefficients for asphalt and soil surfaces are considered constant across all frequencies due to a lack of research on these materials. Typically, studies on sound absorption coefficients are conducted in theatre rooms. Additionally, the density of soil affects the sound absorption coefficient, with higher density materials like solid plywood or concrete reflecting more sound and lower density materials like cork or melamine foam absorbing sound more effectively. In this simulation, the density of soil is set at 1500 kg/m^3, which may not accurately represent real-life conditions in residential areas or the "Los Madronos" Hospital in Madrid, Spain, thus impacting the accuracy of the results. Furthermore, there are many materials which take place in experiment that not considered in simulation such as tree and grass.

In Finite Element Analysis, the accuracy of the results is influenced by the size of the mesh used. According to the theory of finite element analysis, models with smaller element sizes yield more accurate results compared to models with larger element sizes. Through a mesh sensitivity study, it was found that Equation (2.2) accurately represents the relationship between the mesh dependency and the current situation.

3.3 Validation and comparison of result with experiment

Validation and comparison of results is critical for the acceptance of such simulations model. Validation and comparison process adopted from journal by Juan M. Martinez- Orozco and Antonio

Barba [2]. Ariel photograph from Iberpix, OrtoPNOA 2020 CC-BY 4.0 scne.es [2] has been use as plan and cross section for FE-detailed model for berm and metal wall. Ansys is used to draw and simulate a full model and 1/10 scale model by assigning wall and without wall model.

The difference of insertion loss between simulation and experimental result were not far apart. The similarity from the insertion loss result at 5 meters is greater than 25 meters from the wall either in simulation or experiment. Table 1, Table 2, Table 3 and Table 4 show insertion loss value between simulation and experimental result.

Table 1: Insertion loss difference for full model metal wall

Frequency (Hz)	5 m			25 m		
	Exp	Sim	|Diff|	Exp	Sim	|Diff|
31	3.80	5.11	1.31	1.10	4.58	3.48
63	1.80	4.34	2.54	0.80	3.76	2.96
125	2.50	3.32	0.82	2.10	2.73	0.63
250	6.40	2.81	3.59	4.10	2.23	1.87

Table 2: Insertion loss difference for 1/10 model metal wall

Frequency (Hz)	5 m			25 m		
	Exp	Sim	|Diff|	Exp	Sim	|Diff|
310	3.80	5.08	1.28	1.10	4.09	2.99
630	1.80	4.17	2.37	0.80	3.12	2.32
1250	2.50	3.24	0.74	2.10	2.14	0.04
2500	6.40	3.66	2.74	4.10	2.53	1.57

Table 3: Insertion loss difference for full model berm wall

Frequency (Hz)	5 m			25 m		
	Exp	Sim	|Diff|	Exp	Sim	|Diff|
31	4.20	6.44	2.24	2.90	5.28	2.38
63	3.70	6.95	3.25	2.00	5.80	3.80
125	6.20	7.50	1.30	3.90	6.34	2.44
250	7.20	6.75	0.45	3.80	5.08	1.28

Table 4: Insertion loss difference for 1/10 model berm wall

Frequency (Hz)	5 m			25 m		
	Exp	Sim	|Diff|	Exp	Sim	|Diff|
310	4.20	5.91	1.71	2.90	1.49	1.41
630	3.70	6.11	2.41	2.00	1.66	0.34
1250	6.20	6.46	0.26	3.90	1.98	1.92
2500	7.20	7.28	0.08	3.80	3.04	0.76

4. Conclusion

This study met its objective by simulating a roadway model with and without a wall in order to calculate insertion loss. The design and analysis were carried out using SolidWorks and ANSYS software. The data revealed insertion loss tendencies, with higher values at 5 m from the wall compared to 25 m. The study enabled cost-effective testing and optimisation of the design prior to the construction of a physical prototype.

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