IOP Conf. Series: Materials Science and Engineering **800** (2020) 012029 doi:10.1088/1757-899X/800/1/012029

Acoustic and structural design of a highway noise barrier

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Abstract. Highway noise barriers are designed to mitigate the effects of traffic noise along the highway. Noise barriers primarily block the direct path of the sound between the source on the highway and the receiver exposed to the sound. Noise mitigation capability, aesthetics, cost and constructability and structural capacity against wind and earthquake loads are critical parameters to be considered in noise barrier design. The height and length of a noise barrier are determined by acoustical considerations, aesthetics and cost. In addition, the structural design of the noise barrier should meet the established standards. The aim of this study is to evaluate the noise mitigation capabilities, aesthetic features and costs of acoustic designs for the residential buildings located near the urban highway and evaluate the structural performances against wind and earthquake. Through the interviews, the designs higher than 10m are not found acceptable by the residents and also due to the aesthetic concerns the upper part of the noise barrier is set to be constructed as glass. Therefore, the noise reduction capabilities and construction cost and the alternatives that complies with the constraints are determined and the corresponding costs are calculated accordingly. Noise simulation software is used to identify the effectiveness of selected noise barriers and structural analysis and design software is used to evaluate the structural performance. The results show that designed precast lightweight concrete and glass composite noise barrier meet the required noise reduction goal along with a resilient structural performance and affordable cost.

1. Introduction

Despite the recognition of the importance to reduce environmental noise has had a lower priority than that the other environmental problems such as air and water pollution, noise pollution is one of the phenomena that should be addressed in many cities in the world. The adverse impacts of transportation-related noise in general and road traffic noise in particular on the society have gained recognition in the last 40 years in the world where more than 55% of the population has been started to live in urban cities. [1,2]

There are a number of methods for controlling road traffic noise and noise barriers are arguably the most simple, effective and commonly used method among alternatives. Turkey and many other countries have established their national noise barrier standards such as TS EN 1793-1,2,3, EN 1794-1,2,3 and ZTV-LSW 06 [3,4,5]. Noise barriers are commonly used in urban expressways in Japan. In figure 1 noise barriers installed on Tomei Expressway are presented.

Highway noise barriers are designed to mitigate the effects of traffic noise along the highway. Noise barriers primarily block the direct path of the sound between the source on the highway and the receiver exposed to the sound. Noise mitigation capability, aesthetics, cost and constructability and structural capacity against wind and earthquake loads are critical parameters to be considered in noise barrier design. The height and length of a noise barrier are determined by acoustical considerations, aesthetics and cost. Therefore, the need for a noise barrier is primarily designed to meet the acoustic standards; however, the final design is generally shaped by the non-acoustic factors as well.

The aim of this paper is to present a road traffic noise calculation method, road traffic noise modelling and calibration and design of a noise barrier by considering acoustic, aesthetic and structural standards. Section 2 highlights the theoretical concepts of SRM II highway noise level calculation method, in Section 3 road traffic noise modelling of high-rise residential building along the highway is given, in Section 4 noise barrier acoustic and structural design are presented and the corresponding costs are calculated, in the last section the conclusions are drown and the possible areas of further research is discussed.

Figure 1. A noise barrier along Tomei Expressway around Yokohama [Maps Google Image]

2. SRM II highway noise level calculation method

Several acoustic emission and propagation models derived by national standards can be applicable for transportation noise pollution. Generally, models are based on the solution of boundary integral equation of the wave equation in two dimensions and the results are transformed to derive a pseudo-three-dimensional (3-D) solution. [6] Most of highway noise level calculation models are regional and specific for countries such as Denmark's NORD2000 [9] [7], Germany's DIN18005-1 [8] and SCHALL 03 [9], France's NMPB [10] and Dutch's RMR96-SRMII [11]. Since each model is specific to the transport infrastructure of the country in which it is developed, various calibration and correction coefficients are needed when used in another country. When noise mapping became mandatory throughout Europe after the European Directive on the Assessment and Management of Environmental Noise, 2002/49/EC [12], studies on this subject gained momentum. Because as a controversial decision, countries not having country-specific noise prediction model are recommended by the same European Directive to use Dutch SRM II Model. The Republic of Turkey doesn't have its own noise calculation model for transportation noise. However, Dutch SRM II noise calculation model is widely used according to directive of 2002/49/EC and TR/2004/IB/RN/02 in The Republic of Turkey [13].

RMR96 SRM II noise prediction model work on the octave bands such as median frequencies of 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz and two different equations for each road and railway traffics. Road traffic prediction model in SRM II examines road vehicles in three different groups such as light vehicles (lv), medium vehicles (mv) and heavy vehicles (hv) [14]. The corresponding equation for the road traffic noise in RMR96 SRM II is given below:

$$L_{Ei,m} = 10log\left(\frac{Q_m}{v_m}\right) + \alpha_{i,m} + \beta_{i,m}log\left(\frac{v_m}{v_{0,m}}\right) + C_{surface_{i,m}} + C_{H,m} \tag{1}$$

Where i and m are index for octave band and vehicle category respectively. Q, v, and v_0 are mean flow of vehicle per hour, mean speed in km/h and reference speed respectively. This model also contains correction constants such as $C_{surface}$ for road surface type and C_H for inclination of road. Alpha and beta are parameters which determine the sound power level for vehicle categories. The constants are tabulated in the table 1 below.

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Table 1. SRM II Prediction Model Constants for Road Traffic Noise

	alpha			beta		
Octave frequency [Hz]	lv	mv	hv	lv	mv	hv
62	74.5	79.9	84.1	-.05	-0.2	9.8
125	84.5	91.1	91.4	24.6	16.6	11.4
250	89.9	97.1	97.7	27.6	2.5	2.6
500	94.0	100.5	104.8	26.1	26.6	23.2
1000	101.1	103.3	106.5	26.8	22.3	20.8
2000	99.0	100.4	102.4	22.5	16.6	15.0
4000	90.9	93.9	95.6	22.2	16.2	12.4
8000	81.0	85.6	87.0	11.7	-1.9	-3.1

Directive on the Assessment and Management of Environmental Noise demands on cities to produce noise maps [12]. During the producing process, several proprietary software like IMMI [15], SoundPlan [16], CadnaA [17], MITHRA-SIG [18] etc. are used. These software are based on standard methods like SRM II, XPS 31-133 etc. and need several inputs such as transportation networks, buildings, distribution of population and topography.

3. Road traffic noise modelling of high-rise residential building along the highway

3.1. Noise resources and standard limits

According to the Turkish regulation on the assessment and management of environmental noise was first published in 2005, and later amended in June 2010 and 2015, the noise levels are varied with respect to the time of day for the commercial buildings and dense residential areas with noise sensitive locations. The limits are given in Table 2, where the night noise limit is set as 58 dBA [19].

Table 2. Noise Limits

Locations	Existing Roads		
	L_{day} (dBA)	$L_{evening}$ (dBA)	L_{night} (dBA)
Commercial Buildings and Dense Residential Areas with Noise Sensitive Locations	68	63	58

With the increase in urbanization rate the need for high-rise building are also increased. As a result of this, the value of the land is also raised which pushed the contractors to use the construction areas all the way to the borders. Therefore, most of the high-rise buildings in big cities in Turkey are facing highways.

One of the prominent examples of this type of high-noise impacted area is selected as the case study. The residential high-rise complex is located in Istanbul at Beylikdüzü and Esenyurt region. The complex is near a busy arterial that connects Ambarlı Port to a major highway. The volume of traffic and the ratio of heavy vehicles is considerably high on the road. The aerial and the 3D view of the residential complex is given in Figure 2 and Figure 3.

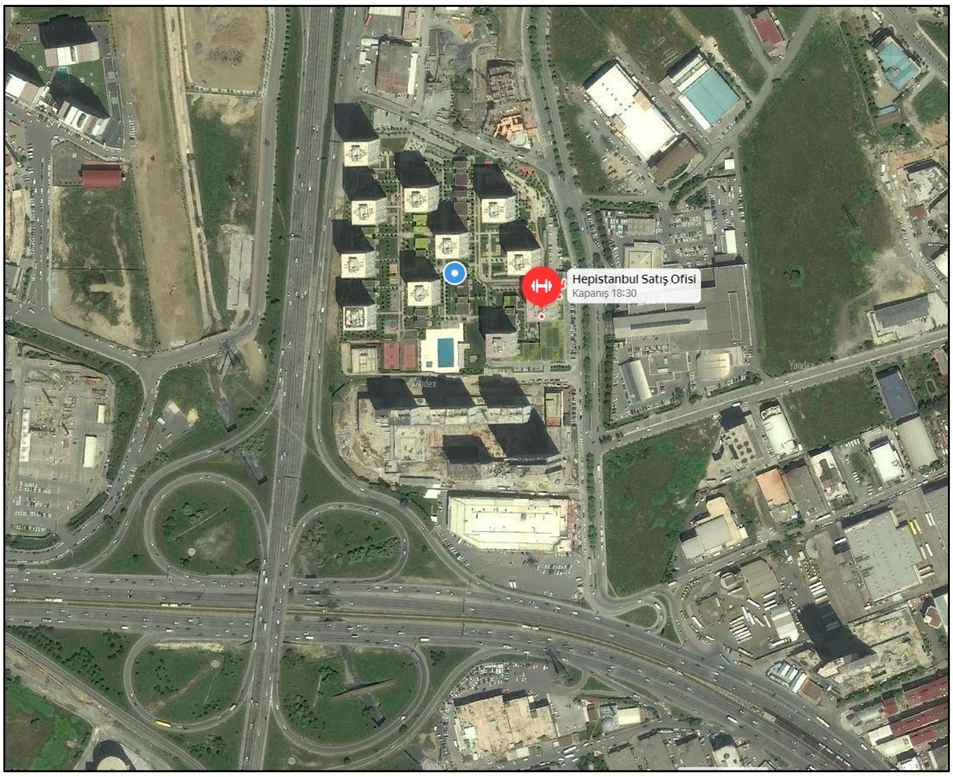

Figure 2. The location of case study

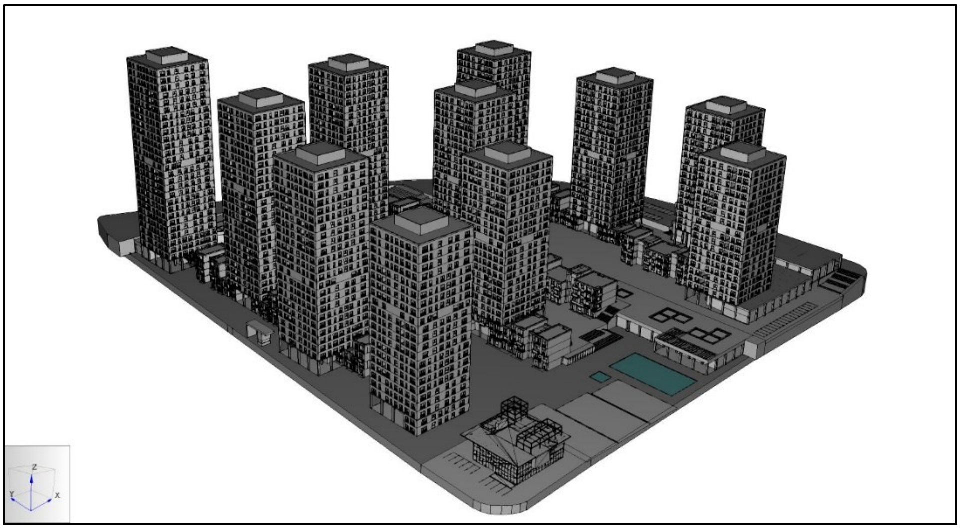

Figure 3. 3D view of residential high-rise complex

3.2. Noise Level Measurements

Noise level measurements were made at noon on 02.09.2019. As the measurement points, the side of the highway, the garden of the residential building on the highway front and the roof of a 4^{th} storey of building on the same front were selected. The results of the measurements are given in figure 4 and noise level statistics are tabulated in table 3. High noise levels are detected on the façade of the building. The legal limit for daylight hours is 68 dB (A) and the measured value in the site yard is above the limit values that is around 71 dB (A).

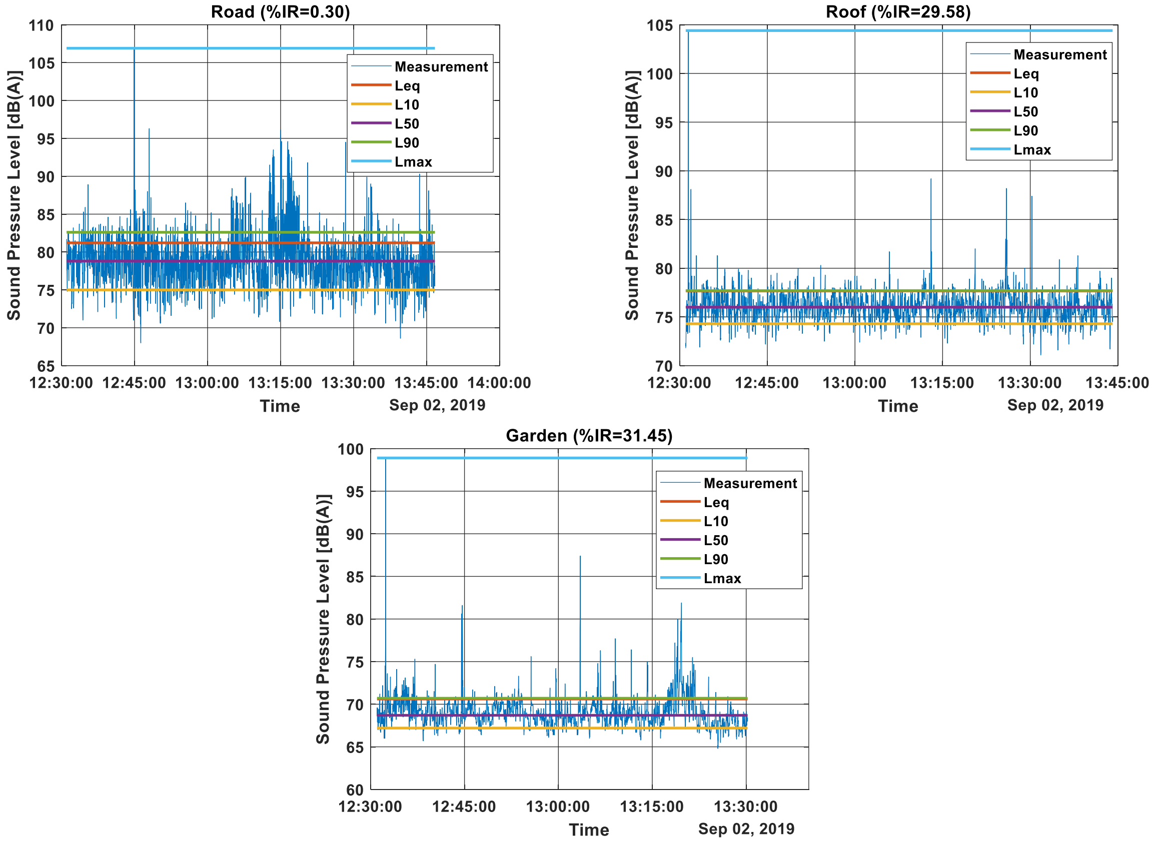

Figure 4. Noise levels measured on site

Table 3. Noise level statistics

	L_{eq} [dB(A)]	L_{10} [dB(A)]	L_{50} [dB(A)]	L_{90} [dB(A)]	IR [%]
Garden	70.61	67.20	68.70	70.00	31.45
Roof (h=12m)	77.67	74.30	76.00	77.70	29.58
Near road	81.21	75.00	78.80	82.60	0.30

The noise model of study area is modelled on IMMI 2018 software, and the topography model was created through NASA's SRTM data. The project area has been brought to its current elevations through the project files obtained from the contractor of the residential complex. It was found that the garden elevation on the façade of the HEP Istanbul housing estate was at 31.2 m. The height of the designed noise barriers is defined at 31.2 m elevation. For the defined heavy vehicle traffic, it is assumed that Ambarlı Port will operate with 75% capacity and handle 3.65 million TEU cargo annually, thus creating a heavy vehicle traffic of 10.000 vehicles per day [20]. It is assumed that the traffic of this heavy vehicle will increase to 830 truck/hour and the average cruising speed will be 65 km/h. Even though the speed limit indicates 50km/h for heavy vehicles it is observed that the heavy vehicle are not complying the speed limits on the road. The measurements were used for the calibration of the noise model and vehicle volume data were used as the calibration variable.

3.3. Modelling and calibration of road traffic noise and exposure levels

Noise levels obtained by noise simulation model and the field measurements are presented in table 4. In this respect, automobile traffic was used as a calibration variable. The measured L_{eq} value and the calculated L_{eq} values are significantly close to each other and the logarithmic relative error is about 1%. Considering the fact that, uncertainty level in noise modelling is widely accepted as 2.5 dBA, it can be considered that the model established in IMMI 2018 software can mimic the actual situation with a high precision. It should be noted that noise levels are affected by environmental variables such as wind and temperature, the results could also vary for traffic volumes and conditions.

Table 4. L_{eq} levels for noise model and site measurements

	L_{eq} [dBA]$_{simulation}$	L_{eq} [dBA]$_{measurement}$
Garden	70.25	70.61
Roof (h=12m)	77.90	77.67
Near road	81.56	81.21

The building blocks are modelled as 3D solids, the receiver points are placed in each floor on the facade and the noise is defined as line source. Figure 5 shows the building blocks and line noise sources. As can be seen from figure 6, the noise levels on the facade of the buildings in the residential complex are above the limits set in Turkish regulation on the assessment and management of environmental noise. The width of the noise resource and the high traffic volume on the road narrow the noise mitigation solution set. Therefore, a simple and cost-effective noise barrier design is proposed for mitigating the impacts of highway traffic noise.

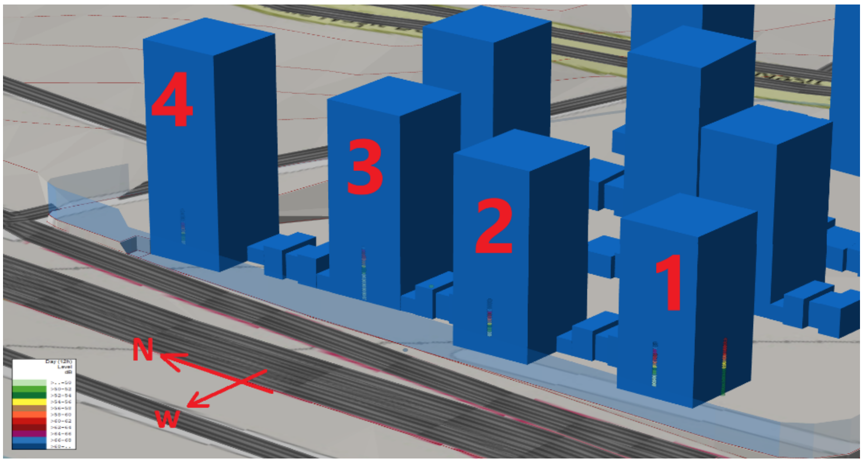

Figure 5. Modelled building blocks in 3D

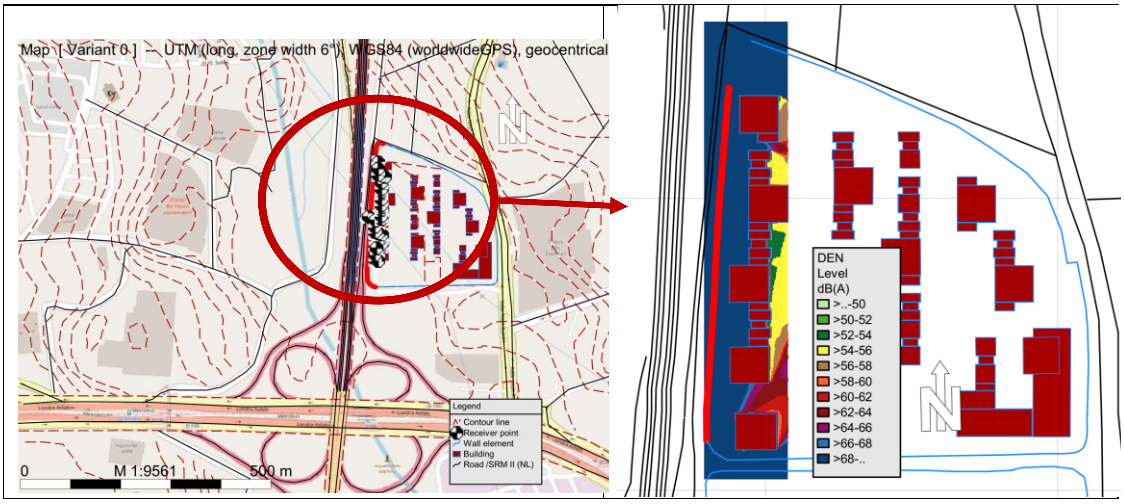

Figure 6. Modelled study area, roads and residential complex

4. Noise barrier design and costs

The acoustical performance of a noise barrier can be measured with the ratio of path length difference to the acoustic wavelength. The diffracted path when a barrier is installed in between noise resource and a receiver is presented in Figure 7 schematically.

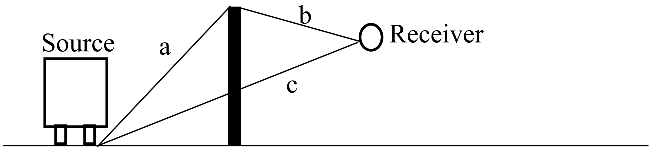

Figure 7. Path length difference

The path difference can be defined as the difference between the direct sound path from source to receiver when there is no noise barrier and the diffracted path when a barrier is installed in between.

$$\delta = a + b - c \tag{2}$$

A non-dimensional variable namely Fresnel number, N, is defined as the ratio of the path length difference, δ, over the wavelength of sound in air, λ. Fresnel number has been widely used in simple models as a performance indicator of a noise barrier.

$$N = \frac{2\,\delta}{\lambda} \tag{3}$$

4.1. Geometric design and acoustic performance

The acoustical performance of a noise barrier designs are evaluated in noise simulation environment. The initial designs higher than 10m are not found acceptable by the residents and also due to the aesthetic concerns the upper part of the noise barrier is set to be constructed as glass. The conceptual design of alternative noise barriers are given in Figure 8.

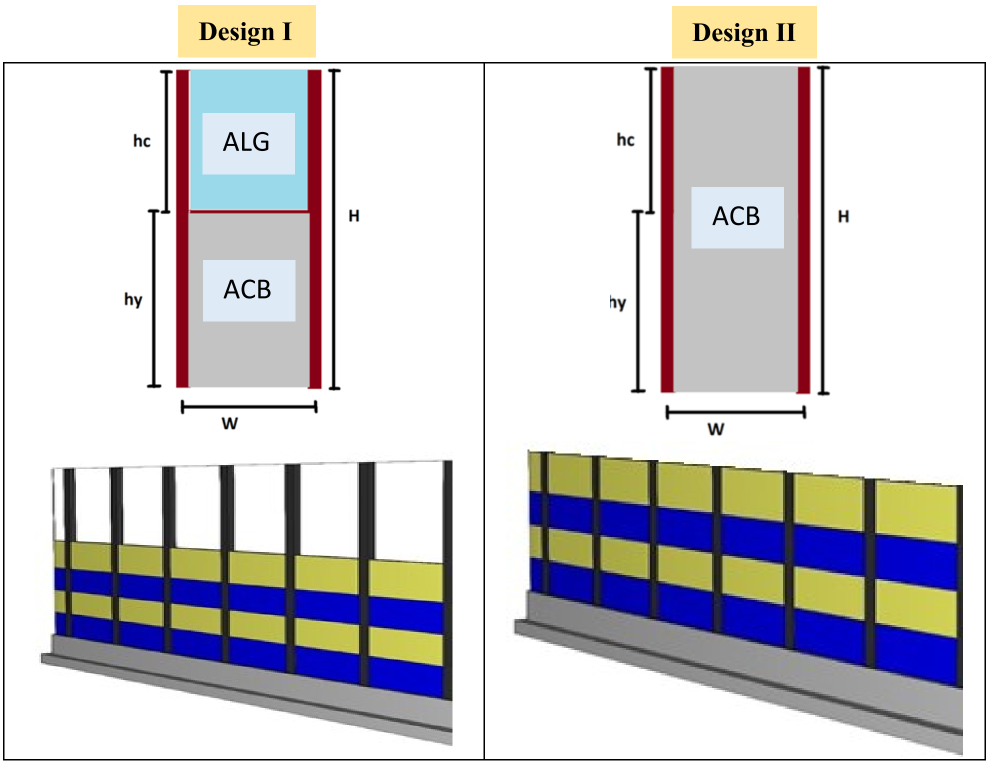

Figure 8. Dimension and materials used in noise barriers

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The unit width is 3m (W) and the total height is 7.4m (H) for both designs. Design I is a composed of a 4.2m (h_y) aerated concrete blocks (ACB) and 3.2m (h_g) of acoustic laminated glass (ALG). ACB's internal structure is comprised of 60%-70% air, and AAC absorbs much more sound than conventional concrete and other materials, effectively reducing sound wave transmission. ALG is produced by joining two or more glass plates under heat and pressure with the help of special acoustic polyvinyl butyral (PVB) layers that provide sound insulation. The thickness of the ACB is 12mm and the unit weight is 30 kg/m^2.

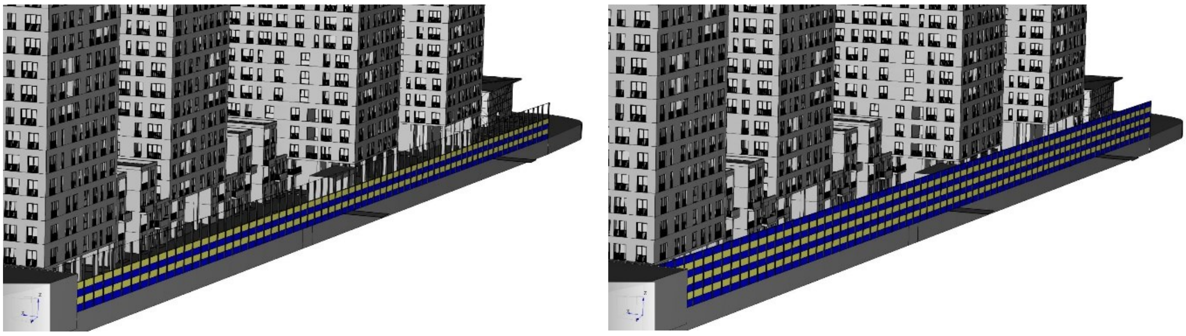

Figure 9. 3D view of Design I and Design II

The acoustical performance of noise barrier designs is evaluated in a noise simulation environment. Both designs provide a reliable highway noise mitigation and the acoustic performance of the designs is statistically indifferent. The receiver points read 79.89 dBA on average for all four blocks' 6th-meter height on the façade of buildings without a noise barrier (NB). In Design I, the noise barriers manage to reduce this average traffic noise level to 66.90 dBA with an average 12.99 dBA reduction where the daytime noise level is limited with 68 dBA. The summary of noise performance of designs are given in Table 5.

Table 5. Noise level comparison with measurement and designs

	Without NB	Design I	Design II
Block 1	79,78	68,56	68,90
Block 2	80,46	66,42	66,76
Block 3	79,12	64,89	65,18
Block 4	80,21	67,76	68,00
Average	79,89	66,90	67,21

The noise maps are given in Figure 10 present the effectiveness of designed noise barriers for the residential complex located near a highway.

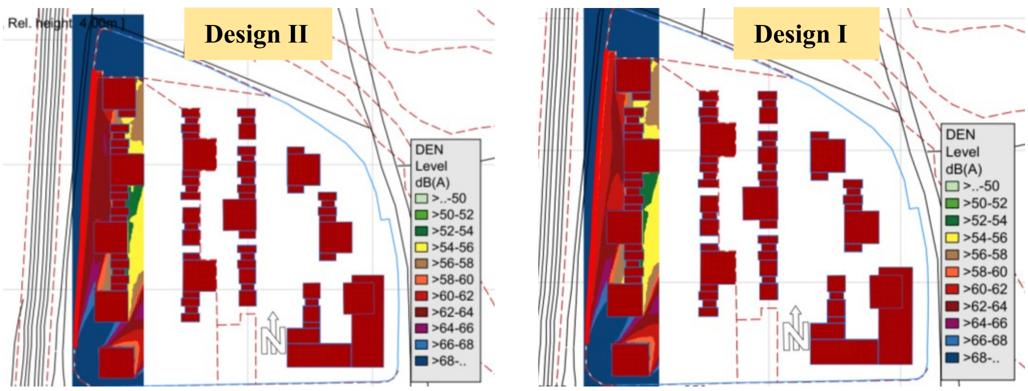

Figure 10. L_{DEN} Noise Maps in dB(A) at H=4m of Design I and Design II

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4.2. Structural design

Steel framing systems are becoming a more preferred structural system due to their ductility and high performance in meeting the horizontal loads such as earthquake and wind. The specifications and regulations prepared for the steel structures create a solid base for the reliable design and practical implementation. The noise barriers discussed in this study is planned to be constructed in an area with both high seismic activity and high wind speeds. Therefore, steel frame is selected as the structural system due to its capability for resisting high seismic and wind loads, along with the additional advantages in terms of precision and construction time.

Considering the earthquake and wind effects, the selection of the appropriate structural system is of great importance. In order to determine the effects of the earthquake on the steel structured noise barrier, Revised Probabilistic Seismic Hazard Map of Turkey [21] is used. Probabilistic Seismic Hazard Map of Turkey is a contour map based on geographic coordinates. The 10% probability of exceedance in 50 years and it is corresponding return period of 475 years of rare earthquake ground motion of a (DD2) is selected form table 6 and the earthquake parameters are determined. S_S is the short period map spectral acceleration coefficient, S_1 is the map spectral acceleration coefficient for 1.0 second period, S_{DS} is the short term design spectral acceleration coefficient, S_{D1} is the design spectral acceleration coefficient for 1.0 second period, PGA is the maximum ground acceleration [g] value.

Table 6. Earthquake parameters

Earthquake Ground Motion Level	DD-2
Local Soil Type	ZC
S_s	1.133
S_1	0.308
S_{DS}	1.36
S_{D1}	0.462
PGA	0.464

The Eurocode-1 [22] regulation was used to determine the responses to the noise barrier due to wind. The basic wind speed, which is one of the most important parameters in wind calculations, should be determined correctly. The fundamental wind speed, which is of great importance in structural calculations, is the wind speed which corresponds to the possibility of exceeding the average 10-minute wind speeds measured in any direction at an open area at 10m height at least once every 50 years [24]. According to Istanbul High Buildings Wind Regulation [24], the basic wind speed for Istanbul is defined as V_b = 25 m / s. If sufficient wind records are available, the actual wind records obtained in the area where the structure will be constructed can be used for the analysis. Wind speed records, depending on the type of land on which the recording is taken (uneven areas, sea shorelines, forest areas, villages, city centres, etc.), surface roughness coefficient, topography coefficient expressing the height of the place where the high structure is located and structures around the high structure. They show different characteristics depending on various factors. In order to obtain basic wind speeds, wind speed data obtained from the Meteorological Data Archive System of the General Directorate of State Meteorological Affairs was used for the region where the noise barrier will be constructed. As a result, the basic wind speed is 28 m/s is taken for the analysis.

The steel frame systems proposed in the study are designed in accordance with the Design, Calculation and Construction Principles of Steel Structures (2016) [25], ASCE 7 (2016) [26], AISC 360 (2016) [27] and AISC 341 (2016) [28]. The structure system model used for the analysis is shown in Figure 11.

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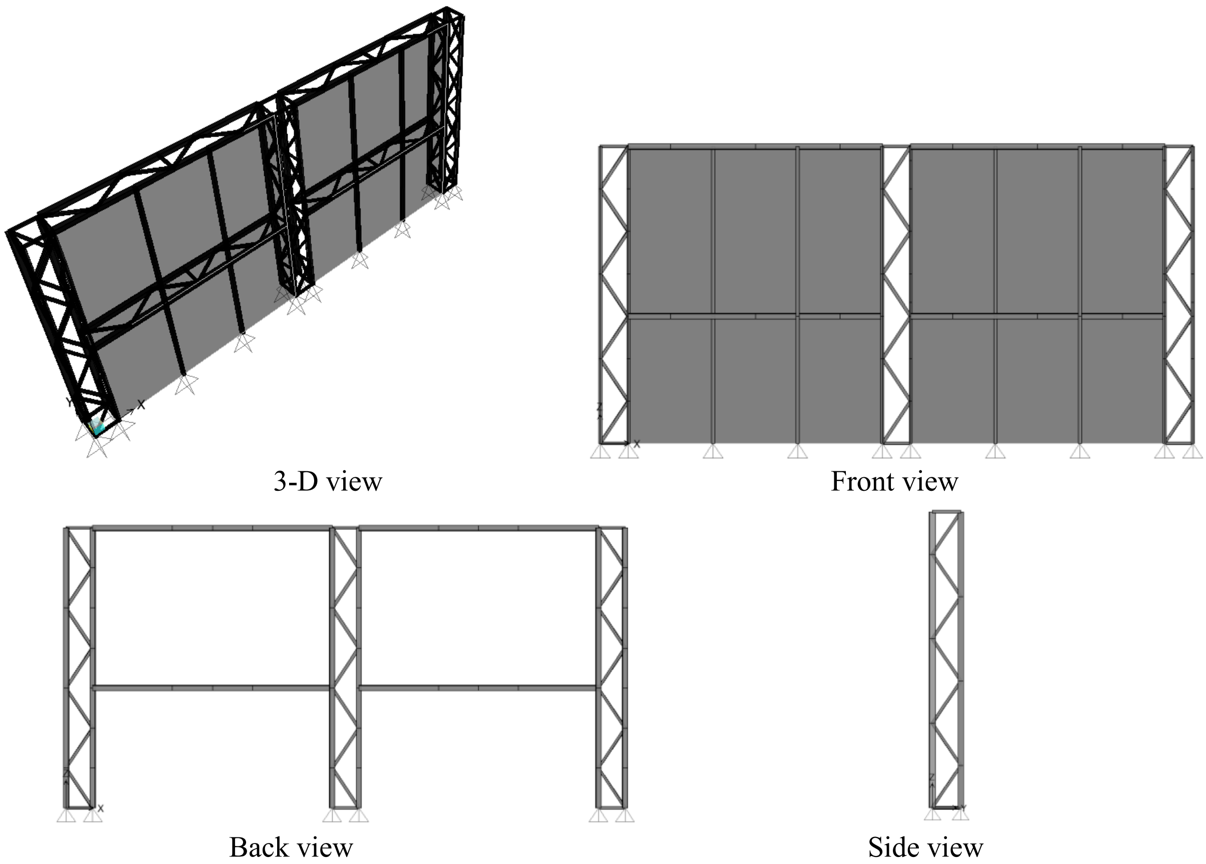

Figure 11. Structural system model

As it is mentioned in the geometric and acoustical design, two different solutions have been proposed to ensure the sound insulation of the noise barrier, which is planned to be 220 meters in length and 7.4 meters in height. It is assumed that the columns of all frames are supported with a simple connection to the foundation. In the structural system, the columns are 1m*1m 3D truss, beams 2D truss, the distance between the columns is 9 meters and the distance between the posts is 3 meters. S275 quality IPE profiles are used in the columns, S235 quality box section profiles are used in beams, trusses and mullions. The system is modelled with SAP2000 finite element program [29]. Linear analysis of the systems was carried out in accordance with the Design, Calculation and Construction Principles of Steel Structures (2016) and AISC 360 (2016) by using load resistance coefficients and design method (LRFD). The profiles selected to meet the requirements of the regulations are given in Table 7. The required amount of steel for both systems was obtained as 45 kg/m^2.

Table 7. Steel members used in the structure

Column	IPE 220
Upright	200-120-6
Column shear	100-100-4
Beam	200-200-6
Beam Shear	100-100-4

4.3. *Approximate cost of designs*

In order to calculate the total cost of noise barriers, the unit material costs and the total amount of construction is determined. The cost of the steel framework, the cost of ACB and the cost ALG is determined for each design. Table 8 presents the total costs of the corresponding designs.

Table 8. The costs of noise barrier designs

		Design I		Design II	
	Unit Material Cost	**Quantity**	**Total Cost**	**Quantity**	**Total Cost**
ACB	115 TL/m^2	924 m^2	106,260 TL	1,628 m^2	187,220 TL
ALG	190 TL/m^2	704 m^2	133,760 TL	-	-
Steel	4 TL/kg	72,260 kg	284,040 TL	72,260 kg	284,040 TL
Concrete	450 TL/m^3	110 m^3	49,500 TL	110 m^3	49,500 TL
		TOTAL	**573,560 TL**	TOTAL	**520,760 TL**

The unit cost of ALG is higher than ACB however, the acoustic performance of ALG+ACB is relatively better. Hence, Design I has a higher cost with a slightly better acoustic performance. In addition to that Design I is considered as more acceptable by the residents which makes the design to be preferable.

The average cost of the composite type noise barrier, Design I, is around 350 TL/m^2. This value decreases to 320 TL/m^2 in Design II where only ACB is used. Reinforced concrete noise barriers unit cost is given as 270 TL/m^2 by Calis et al. in 2018 [30]. Similarly, the unit cost of the 2A group of sheet piles and retaining walls in 2019 is given as 450 T TL/m^2. When all these unit prices are evaluated, the total cost for the composite ACB and ALG design, Design I, is expected to be around the 500 TL/m^2 for 2019 prices.

5. Conclusion

In this paper, the noise mitigation capabilities, aesthetic features and costs of acoustic designs for the residential buildings located near the urban highway is evaluated and also structural performances against wind and earthquake are examined. Design I presented a better acoustic performance along with a lower total cost. There is no established noise barrier geometric and material optimization method for highway traffic noise mitigation. In order to find the best design, the designer should consider not only the noise level standard limits, but also the cost, aesthetic and the structural standards. However, an acoustic optimization method is planned to be developed to generate an optimum dimension of a noise barrier.

According to the results, a complete glass noise barrier design can be examined further. However, due to the transparent nature the thermal and aesthetic consequences along with the resilience against the traffic accidents of a full glass design should also be researched in detail.

References

[1] Commission of the European Communities, Green Paper on “Future Noise Policy”, COM (96)540, Brussels, November 1996

[2] The European Parliament and the Council of the European Union, Directive 2002/49/EC, Assessment and management of Noise, 25 June 2002

[3] TS EN 1793-1,2,3 “Road traffic noise reducing devices — Test method for determining the acoustic performance Part 1: Intrinsic characteristics of sound absorption”, EN 1793-1, (1997). “Road traffic noise reducing devices, Test method for determining the acoustic performance Intrinsic characteristics of airborne sound insulation”, EN 1793-2, (1997). Road traffic noise reducing devices, Test method for determining the acoustic performance, Part 1: Normalized traffic noise spectrum”, EN 1793-3, (1997).

[4] EN 1794-1 and 2 “Road traffic noise reducing devices, Non-acoustic performance, Part 1: Mechanical performances and stability requirements”, EN 1794-1, (1998) and “Road traffic noise reducing devices, Non-acoustic performance, Part 2: General safety and environmental requirements”, EN 1794-2, (1998)

[5] ZTV-LSW 06, Forschungsgesellschaft für Straßen und Verkehrswesen: Zusätzliche Technische Vertragsbedingungen und Richtlinien für die Ausführung von Lärmschutzwänden an Straßen, Ausgabe 2006 (ZTV-Lsw 06), Köln
[6] Martin, S. J., and D. C. Hothersall. "Numerical modelling of median road traffic noise barriers." Journal of Sound and Vibration 251.4 (2002): 671-681.
[7] Jonasson, H., Storeheier, S. (2001) Nord 2000. New Nordic Prediction Method for Road Traffic Noise; Borås, Sweden.
[8] Noise Abatement in Town Planning—Part 1: Fundamentals and Directions for Planning; DIN 18005-1. 2002. [online] Available at: https://www.beuth.de/en/standard/din-18005- 1/46725515 [Accessed 1 Oct. 2019].
[9] Gesetze-im-internet.de. (2019). Berechnung des Beurteilungspegels für Schienenwege (Schall 03). Anlage 2 16. BImSchV - Einzelnorm. [online] Available at: https://www.gesetze-im-internet.de/ bimschv_16/ anlage_2.html [Accessed 1 Oct. 2019].
[10] Dutilleux, G.; Defrance, J.; Écotiere, D.; Gauvreau, B.; Bérengier, M.; Besnard, F.; Le Duc, E. (2010). NMPB-routes-2008: The revision of the french method for road traffic noise prediction. Acta Acust. United Acust. 96, 452–462
[11] Reken-en Meetvoorschrift Railverkeerslawaai'96, (1996) Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer
[12] Directive on the Assessment and Management of Environmental Noise, 2002/49/EC from 25.06.2002.
[13] Çevresel gürültü değerlendirmesi ve yönetimi ile ilgili ab direktiflerinin uyumlaştirilmasi ve uygulamamalar avrupa birliği eşleştirme projesi TR/2004/IB/EN/02
[14] AR-INTERIM-CM (CONTRACT: B4-3040/2001/329750/MAR/C1), Adaptation and revision of the interim noise computation methods for the purpose of strategic noise mapping, WP 3.1.2: Road traffic noise - Noise emission: databases
[15] Woelfel.de. (2019). Wölfel - IMMI. [online] Available at: https://www.woelfel.de/en/ products/ immi/ [Accessed 2 Oct. 2019].
[16] SoundPLAN GmbH, L. (2019). Home - SoundPLAN GmbH. [online] Soundplan.eu. Available at: https://www.soundplan.eu/english/ [Accessed 2 Oct. 2019].
[17] Software, C. (2019). CadnaA – State-of-the-art Noise Prediction Software. [online] DataKustik GmbH. Available at: https://www.datakustik. com/products/cadnaa/cadnaa/ [Accessed 2 Oct. 2019]. [18] Geomod. (2019). MithraSIG - Acoustic simulation software software for exterior area. [online] Available at: https://www.geomod.fr/en/land-geomatic/mithrasig/ [Accessed 2 Oct. 2019].
[19] Turkish regulation on the assessment and management of environmental noise. (2010). [Online], Available at:https://www.mevzuat.gov.tr/Metin.Aspx?MevzuatKod=7.5.14012&MevzuatIliski=0&source Xml Search %C3%A7evresel [Accessed 2 Oct 2019].
[20] Kapasite ve Elleçleme Bilgileri. (2019). [online] Available at: http://www.mardas.com.tr/tr-TR/kapasite-ve-ellecleme-bilgileri/4/39/ [Accessed 4 Sep. 2019]
[21] Revised Probabilistic Seismic Hazard Map of Turkey [online] Available at: https://tdth.afad.gov.tr/, 2018
[22] Eurocode 1: Actions on Structures. Part 1-4: Wind actions. ENV-1991-1-4:2005, C.E.N., European Committee for Standardization, 2005
[23] Türkiye Bina Deprem Yönetmeliği, Afet ve Acil Durum Yönetimi Başkanlığı, Ankara, 2018
[24] İstanbul Yüksek Binalar Rüzgâr Yönetmeliği (İYBRY), Deprem Mühendisliği Anabilim Dalı Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü Boğaziçi Üniversitesi Çengelköy, İstanbul, 2009
[25] Çevre ve Şehircilik Bakanlığı. Çelik Yapıların Tasarım, Hesap ve Yapım Esasları, , Ankara, Türkiye, 2016
[26] American Society of Civil Engineers (ASCE), "Minimum Design Loads for Buildings and Other Structures", American Society of Civil Engineers, Reston, VA, 2016

IOP Conf. Series: Materials Science and Engineering **800** (2020) 012029 doi:10.1088/1757-899X/800/1/012029

[27] ANSI AISC 360-16, “Specification for Structural Steel Buildings”, American Institute of Steel Construction, Chicago, IL, 2016
[28] ANSI/AISC 341-106, “Seismic Provisions for Steel Structural Buildings”, American Institute of Steel Construction, Chicago, IL, 2016
[29] SAP2000, Computers and Structures Inc., Berkeley, California, U.S.A
[30] Çaliş M and Öztürk Z. "Beton Gürültü Bariyeri İçin Perlit Kaplama ve Maliyeti." Teknik Dergi 29.3 (2018): 8433-8457