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A Short Review of Road Noise Barriers Focusing on Ecological Approaches

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Abstract

The enormous growth in the transport sector in the last few decades has led to substantial rise in the noise levels. This article is a review of the literature related to highway noise abatement, carried out across different regions, to illustrate the effectiveness of noise barriers and highlight some eco-friendly alternatives. Different types of noise barriers and their essential parameters, such as the type of material used, design attributes, attenuation, cost-effectiveness, and life-cycle cost analysis (LCCA) have been emphasized. Cost of material used is also a prime concern during the design of the economic noise barrier. Accordingly, the cost analysis of different materials was carried out using a specialized tool. The paper encourages the use of recyclable wastes for the construction of ecological noise barrier further, a cost-effective and eco-friendly material, namely bottom ash is suggested with an appropriate design for noise reduction.

1. Introduction

Despite of different research being carried out to curb noise pollution; it has become an important matter of concern from few decades. Recently reported data of the Central Pollution Control Board of India (CPCB) had created an alarming scenario across the country as it indicates noise pollution levels in 9 metropolitan cities exceeds the permissible levels [1]. According to the World Health Organization (WHO), it is the third most hazardous environmental type of pollution forth going only after air and water [2]. It is the cause of various health-related issues such as hearing impairment [3], hypertension [4], cardiovascular problems [5], annoyance [6], and sleeps disturbance [7]. According to a study, heart attack, high blood pressure, and stroke rates increase from 7% to 17% for 10 dB increase in road traffic or aircraft noise [8]. Also, 90% of the people in the city of Varanasi confirmed traffic noise as a primary cause of a headache, high blood pressure (BP) problem, dizziness, and fatigue [9].

One of the significant sources of noise pollution is road traffic noise caused by collective sound energy disgorging from motor vehicles. The noise of tires rolling on the roads is found to be the most significant contributor to highway noise, which increases with higher vehicle speeds. Using pavement surface made up of Rubberized Asphalt Concrete (RAC) is often used to reduce tire noise. The numerous studies led in the U.S. and European countries for pavement surfaces made of dense-graded hot mix asphalt (HMA), open-graded asphalt friction course (OGFC), Portland cement concrete (PCC) pavements, and stone matrix asphalt (SMA) reveals 4 to 6 dB(A) reduction in noise levels.

This article focusses on noise barriers which is the widely accepted solution to mitigate road traffic noise. A noise barrier is a stable structure built between the source and the receiver, which acts as an obstacle for noise to reach the receiver, as illustrated in Figure 1. It mainly works on the principle of reflection, diffraction, and absorption. As soon as the noise wave encounters a barrier, it may reflect towards the source side, diffract through the edges of the wall or get absorbed by the barrier. It may be possible that all the three phenomena concur to the sound pressure level at the receiver. It depends on the type of material used for the construction of the barrier. Based on these principles, noise barriers are mainly classified into two categories: reflective and absorptive type. Mostly reflective type noise barriers are used in India. The commonly used materials for building a noise barrier include concrete, wood, metals (steel and aluminium), transparent materials, earth berms, etc. [10].

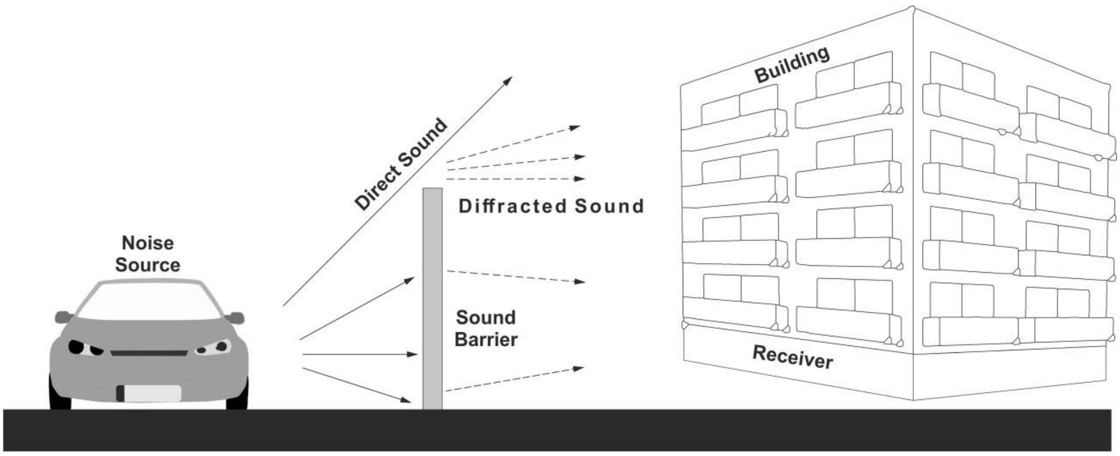

Figure 1. Sound barrier shields the receiver from direct exposure to noise.

It was first in 1968, when the noise from a nearby highway caused disturbances in the outgoing activities of Hollywood Bowl, thereby resulting in the construction of the first noise barrier named 'I-680'in Milpitas, California, USA [11]. Since then, several noise barriers have been constructed in many countries, particularly in developed nations. Alone in the United States of America (USA), 2205 linear miles of barriers were constructed up to 2004 [12]. The first noise barrier in India was built in December 2010. The project was implemented by the Mumbai Metropolitan Regional Development Authority (MMRDA) and was constructed between Kala Nagar and Income Tax building junction [13]. Although noise barrier is the most reasonable mitigation measure to control noise, however, cost-effective design, improving effectiveness, utilizing waste materials and life cycle of noise barrier materials are still some of the current challenges before many researchers. The paper aims to describe the possible consequences of road noise pollution and to study different noise mitigation measures. The literature related to roadway noise reduction strategies have been reviewed. Also, insights on possible approaches for roadway noise mitigation and preferable cost-effective ecological solutions are discussed.

2. Materials and methods

To study the various techniques suggested or implemented so far to improve the effectiveness of noise barriers for road traffic noise mitigation, a review of the wide range of literature was carried out that included 36 journal papers, 6 conference papers, 4 reports, 3 articles, 1 chapter and 3 standard guidance methods. The study used methods of "string search" in search engines such as Google, "database search" (Elsevier, Springer, Google Scholar, Archives of Acoustics, Noise and Health, Applied Acoustics, De Gruyter, etc.), and "conference proceedings search." String searches included sets of terms, namely "noise barriers", "noise pollution", "cost-effectiveness of noise barriers", "vegetation belts", "berms", "concrete noise barriers", "sound absorbing materials", "cost analysis", "design of noise barriers", etc.

All the relevant and recognized articles and papers were read in full, and these papers were found useful in collecting information and storing the necessary details related to the specified topic. The comparative cost analysis of different barrier materials was carried out with a specialized online tool called "Noise Barrier Cost Calculator" designed by the New Zealand Transport Agency. The cost values obtained using this tool does not provide the exact idea, as per the selection of a particular barrier; however, it can be used for an initial assessment.

3. Results and discussion

In-depth review of all the existing literature in response to road induced noise impacts divulge copious noise abatement options such as noise barriers, earth berms, vegetation screening, modification in pavements and few other new opportunities which are either in the development stage or at the conceptual phase that can be realistic in the future to mitigate road noise. Although, all the concepts to reduce the road induced noise are susceptible to pros and cons concerning effectivity, feasibility, and costing bearing for implementation.

A detailed review of different types of noise barriers currently in use and their acoustic performances with respect to atmospheric and ground conditions is described by Ekici et al. [14]. The work describes the potential use of modeling techniques for the determination of barrier performances. The designing of a noise barrier using waste and recyclable materials is fairly a new idea as it is challenging to implement waste to wealth concept. The available research work done in this area is limited, but still it can be very helpful in the development of new materials useful in designing economical noise barriers. The available research has stated that the use of waste and recyclable materials in addition to the noise barrier construction materials can provide a reduction in sound levels. Since, each material has different insertion loss and sound insulation properties, which makes it more effective noise absorber material. The literature has been thoroughly discussed to investigate the most potential, feasible and reasonable noise mitigation approach amongst all the noise abatement options. After carrying out a detailed study and going through various works of literature, the noise barriers were classified into design material, and accordingly, divided into the following categories.

3.1 Vegetation belts as noise barriers

The effectiveness of vegetation as noise barriers has always been a subject of debate for many years. A general ideology that strikes one's mind is that vegetation belts may not be as much effective as other noise barriers. However, there are many shreds of evidence available which act as proof that vegetation belts can provide a considerable attenuation if they are present in sufficient depth and density. Effectiveness of Bamboo plants as noise barrier in mitigating road traffic noise was studied by Leeuwen et al. [15]. The study showed that a 5m tall and 6m thick bamboo noise barrier gave better noise mitigating performance than compared to a 3m tall conventional noise barrier.

The noise reduction by six tree belts in Taiwan has been examined for relative attenuation. The parameters taken into consideration were visibility, the height of tree belt, the width of tree belt, the height of receiver and noise source and the distance between the noise source and receiver [16]. A multiple regression model was developed, and subsequently, all these parameters were incorporated in the regression model to obtain three dimensionless parameters namely h' (receiver and noise source height/ tree height), d' (distance/ tree height) and m' (belt width/ visibility). It was concluded that tree height and belt width were directly proportional to relative attenuation, whereas visibility, receiver and noise source height, and distance had an inverse relation. Also, the tree belts show good noise reduction effect when d'<=8 and h'= 0.15 or 0.3. Significant work of the use of vegetation in noise attenuation was studied by Aylor et al. [17]. The study describes foliage, stems, ground conditions as important parameters for sound attenuation near the ground. A similar study of sound propagation through vegetation was studied by Fricke et al. [18].

Similarly, the effectiveness of bushes in roadside noise reduction was investigated in Konya, Turkey by Onder et al. [2]. Different types of plant species were divided into three groups according to the distance of the bushes from the source taken as 7 m, 11 m, and 20 m and 5 m, 9 m, and 20 m of plant width respectively. Then the decreasing noise level in decibels was measured and calculated accordingly. From the 1st group of plant species, the highest attenuation obtained was 6.3 dB(A), from the 2nd group 5.5 dB(A) and from the 3rd and the last group it was 6.2 dB(A). From these results, it was concluded that the decrease in the noise level or the attenuation obtained depended on three parameters namely species of plant used as a barrier, distance of the barrier from the source, and plant width.

Analysis of the effectiveness of vegetation belts to attenuate road traffic noise in the eminent cities (Dehradun, Pantnagar, and Haridwar) of Tarai region of India was done by Tyagi et al. [19]. Noise level measurements were recorded for 30 minutes at each site at different 1/3rd octave frequencies. As per the obtained results, vegetation belts can act as an effective noise reduction medium provided that they are thick enough so that their canopy is dense. The attenuation achieved at low frequencies is approximately 15 dB while at higher, it is between 15 dB to 20 dB. Also, a significant attenuation of 15 dB or more is obtained at the critical middle range of frequencies (1-4 KHz). However, average attenuation realized was in the range of 3.4 to 9.9 dB(A). These results vary from that obtained in case of Onder et al. [2] as the bushes are comparatively lesser in height than the vegetation belts in this case. Effect of anthropogenic noise on birds is described by Slabbekoorn et al. [20], the paper discusses the construction of noise barrier between the noise source and the habitats of the bird will prove useful in the reduction of noise levels. Emphasis is given to the use of vegetation as barrier across the bird habitat.

Insertion loss can also be considered a significant parameter in deciding the effectiveness of vegetation as Halim et al. [21] carried out a comparative study regarding the effectiveness of vegetation, hollow concrete block and panel concrete as noise barriers in the Klang Valley region aspiring to bridge the gap due to lack of literature in Malaysia.

The noise measurements were carried out for weekdays comprising of five days (Mon-Fri) of the week and weekends (sat-sun) each with two hours of monitoring. Due to the varying trend of vehicular traffic on the roads, the author might have chosen weekdays and weekends for measuring noise to study in detail about the noise trend. From the results, it was concluded that vegetation had the least insertion loss (as illustrated in Figure 2) amongst the three noise barriers followed by concrete hollow block and panel concrete showed the highest insertion loss. Seasonal changes in trees are also an important factor which affects noise attenuation, Maleki et al. [22] conducted an experimental study on various trees in different seasons and found that during the summer season there was more noise attenuation compared to other seasons like autumn, and winter for having more leaves and branches in the trees.

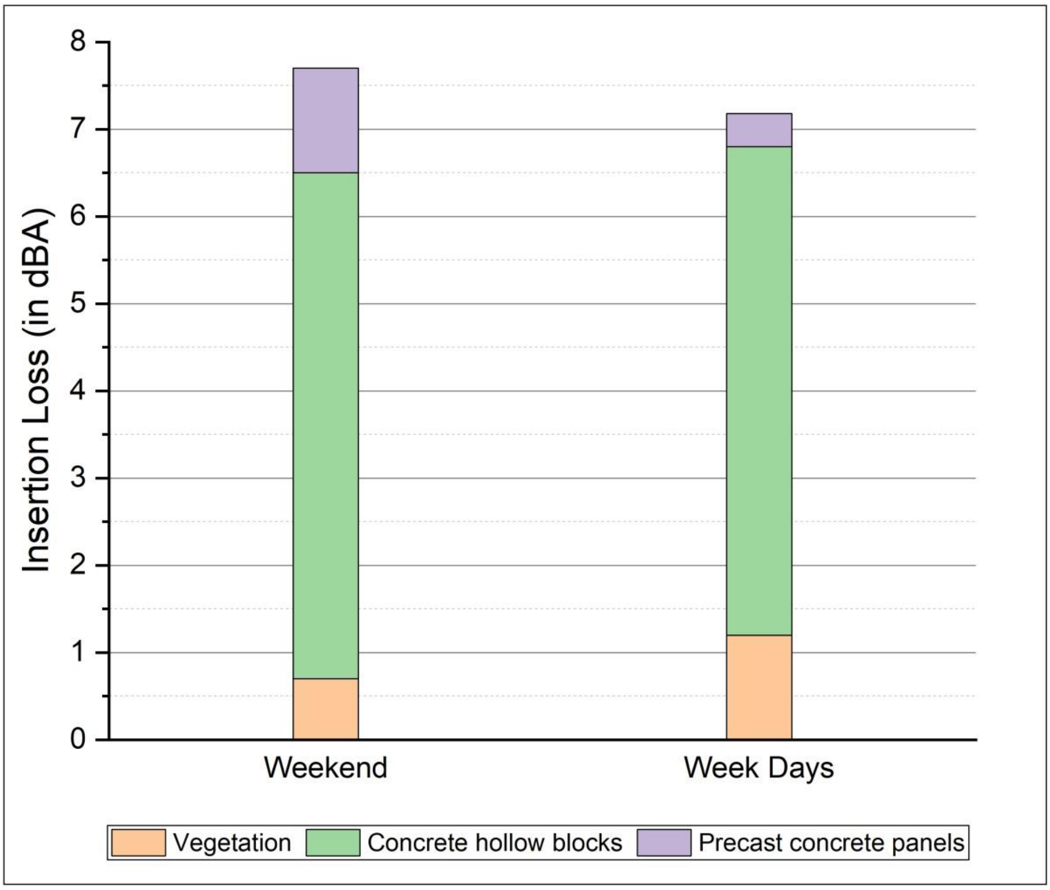

Figure 2. Comparison of different noise barriers verses insertion loss they offered.

Use of a low vegetated noise barrier to determine its acoustic and perceptual effects were studied by Nilsson et al. [23]. The barrier yielded a noise reduction of 4 dB(A) as compared to noise levels without barrier and also improved the perceived acoustic environment making it calmer and less unpleasant. The use of vegetation helps in perceptual reduction of noise by producing a masking effect such as sound produced by the movement of leaves, branches and also by insects, birds, etc. These can be another effective noise mitigation method which can be achieved with the help of vegetation. Renterghem et al. [24] studied road traffic noise propagation by 3D finite-difference time-domain calculations. A vegetation belt of limited depth of 15 m containing periodically arranged trees along a road were adopted for the study. It was found that as the diameter of stem of a tree increases and spacing decreases, traffic noise insertion loss is more pronounced for each planting scheme considered. It was predicted that significant noise reduction can be achieved by providing a tree spacing of less than 3m and tree stem diameter of more than 0.11 m.

Apart from the advantages, all the possible consequences must also be taken into consideration before opting for vegetation as barrier. Besides various merits of using vegetation belts as noise barriers a major demerit is the danger of catching fire by these belts. Tree belts and bushes can catch fire thereby putting the life of nearby people at risk and can also cause loss of resources. Therefore, it must be made mandatory to look after their suitability in a particular area and in case it is adopted mechanisms for prevention from fire must be made available.

3.2 Concrete noise barriers

Concrete noise barriers have always been the first choice for road traffic noise mitigation as they provide noteworthy noise reduction. U.S Department of Transportation also confirms that effective noise barrier can reduce noise in the range of 10 to 15 dB(A) [25]. Furthermore, to increase their noise reduction ability, mounting of some external structure also offers additional noise reduction. Also, some of the results of recent studies have indicated that there is an increase in the attenuation provided by concrete barriers when modified as per design. Morgan et al. [26] examined the life cycle of noise barrier materials from various works of literature and concluded that the service life of concrete noise barrier materials is more than 50 years, which is much effective compared to the rest.

Tram traffic noise can also be reduced by concrete barriers as done in the residential areas near Drzic Avenue in the city of Zagreb in Croatia. In order to estimate the effectiveness of low noise protection barriers as a measure for tram traffic noise mitigation, Ahac et al. [27] developed prediction models and calculations were carried out based on noise computation package of Lima and Dutch RMR 1997 method for estimation of rail traffic noise as European interim calculation method defined by Regulations. Then these were verified by the data obtained by field measurements, and the results were considered précised if the difference between the measured values and modelled values of noise levels is less than 3 dB(A). According to the obtained results, this difference for daytime is 1.8 dB(A) and for a night is 2.5 dB(A), both of which are in the satisfactory range. Further, these results were plotted on noise maps, and it was concluded that low noise protection barriers with a height of 1.2 m offer attenuation of about 10 dB(A) for tram traffic noise mitigation.

3.3 ASE noise barrier

Active control technologies are seen to be effective in sound control at low frequencies [28,29]. In 2001, An Active Soft Edge (ASE) noise barrier, as shown in Figure 3 was developed and tested by Ohnishi et al. [30]. The basic principle used was the reduction in the diffracting noise at the top by decreasing the sound pressure on the surface of the ASE cell. The improvement in the attenuation was about 5 dB as compared to a conventional noise barrier. Ise et al. [28] performed basic theoretical and experimental investigations to improve the performance of passive noise barriers. An active control system was composed and its adaptability was confirmed using Fresnel-Kirchhoff diffraction theory. ½ scale model experiments were also conducted in a hemi-anechoic room to investigate the effectiveness of the active noise barrier. The study has examined only one channel active control. Both the experiments confirmed the considerable efficiency of active noise barrier for sound attenuation at low frequencies.

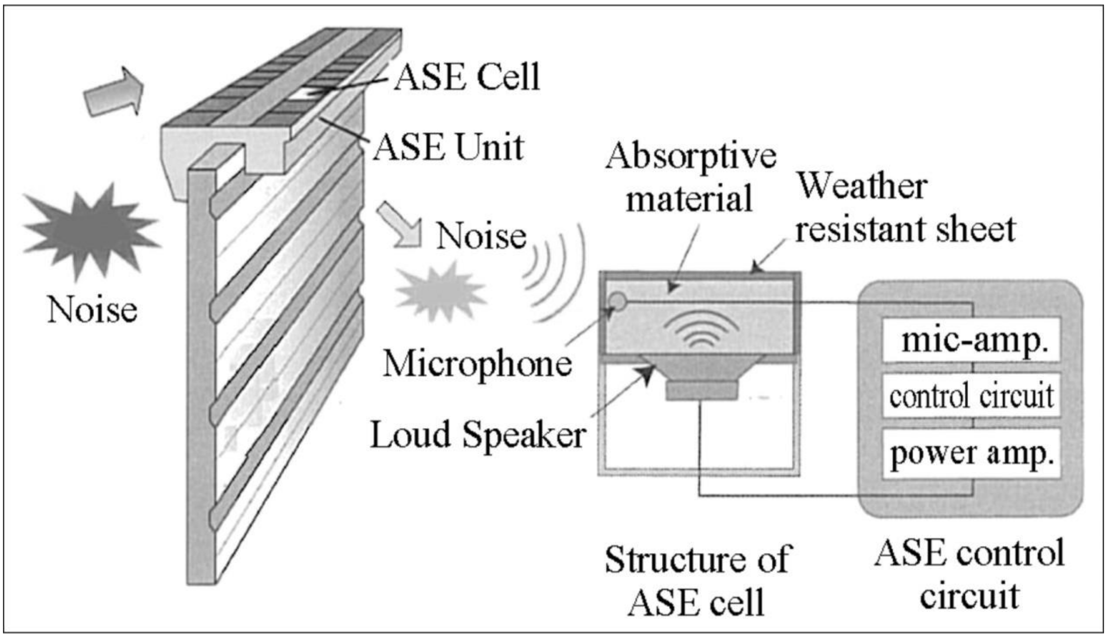

Figure 3. ASE Noise Barrier, Source: Proceedings of the18th International Congress on Acoustics, 1041-1044

Guo et al. [29] used a multi-channel active control system to create quiet zones on top of the barrier thereby increasing the insertion loss of the barrier. The obtained experimental results confirmed that an active noise control device arranged with proper arrangement of control systems achieves noise attenuation. The results confirmed the increased effectiveness of active noise control devices at low frequencies. Kwon et al. [31] has described about the use of active noise control techniques for the management of construction noise. Nowadays, nearly every country suffers the problems arising from the noise emitted by construction works so the study gives a remarkable insight on such a topic. The performed work has aimed to suggest a noise management model and to encourage the applicability of active noise control techniques over passive noise control. Simulations were conducted in order to study the efficiency of active noise control in reducing noise emerging from construction equipment's. Results found the efficiency to be significantly achieved at low and mid frequency bands below 1000 Hz. Besides these the work has also provided with measures not only to reduce noise but also to prevent from consequences such as disputes and delays resulting from conflicts due to improper construction practices related to noise.

3.4 Use of diffusors

Emphasis was laid on the use of primitive root sequence diffusers (PRD) on top of the noise barrier and analysis of their acoustic efficiency on environmental T- shaped noise barrier was carried out by Monazzam et al. [32]. A 2D Boundary Element Method (BEM) was used to predict the insertion loss of the respective barrier. The insertion loss of another similar diffuser named quadratic residue diffuser (QRD) was also predicted for the study. Comparison between different models of PR and QR diffusers has been made. The results indicated that at low-frequency range the barrier models "PR4" and "QR4" almost perform the same. However, the PRD's began to demonstrate some higher improvement as compared to the QRD's between the frequency range of 160 Hz – 2 KHz, excluding the frequencies 315 Hz, 1 KHz and 1.25 KHz where its efficiency is low, both for far-field and areas close to the ground. It is also concluded that the PRD is less frequency dependent. The amount of improvement for PRD in terms of insertion loss for a far field is about 2-3 dB, whereas it can rise up to 4-6 dB for QR4 barrier model. Barriers are needed to be built over flyovers as they also face a huge traffic rush these days. Noise levels for the city of Lucknow were studied when the flyover built over the railway crossing connecting NH 24 to NH 28 interfered with the activities of the nearby college, IET (Institute of Engineering and Technology), Lucknow. The noise level predictions were carried out using a modified FHWA model. All the collected parameters from the field study and noise levels from FHWA model were used as inputs to the excel program, and with the trial and error method calculated the height of the noise barrier to be built over the flyover. Shukla et al. [33] predicted the height of the barrier to be 4.2 m from the floor level of the flyover to reduce the noise level from 63.7 dB to 55.0 dB.

3.5 Noise reduction devices

Diffraction index difference can be considered as the main parameter to distinguish between the noise reduction devices installed at the top edge of the noise barrier. The acoustic effectiveness of these barriers has been compared with barriers with a plain top edge by Piechowicz et al. [34]. The added devices are categorized into three different shapes, namely A, B and C as depicted in the literature. The values for diffraction index differences were about 2 dB for B & C type added devices. However, for type A it was found to be 3 dB. It was concluded that these values are not significantly high as expected. The history of designing noise barriers since the 1970's in Japan is best described by Yamamoto et al. [35]. The study focuses on placing a noise reducing device at the top edge of the barrier. Different shapes for noise reducing devices were considered, such as cylindrical and mushroom type. It was observed that both cylindrical and mushroom-shaped devices offer the additional insertion loss of 2 dB, but the mushroom-shaped barrier is mostly preferred as it reduces the visual impact caused by noise barriers. Further, the hollow space available in the mushroom type device was utilized as a planting box for growing plants. But this idea turned out to be a failure due to maintenance problems and these were not implemented as noise barriers to expressways.

Defrance et al. [36] studied efficiency of a T-shaped diffracting device which works as an absorbing cap for increasing barrier efficiency. It was 0.85 m wide and 0.25 m thick and was made up of agglomerate of rough wood shavings. With the help of MICADO software the acoustical efficiency of the cap for different diffraction angles and path differences was determined. Calculations were performed using methods such as Boundary Element Method (BEM) and Maximum Length Sequence Technique (MLS). The measurements made with MLS show good agreement with the MICADO calculations which validated the BEM approach. Garai et al. [37] has discussed about the standard developed by European Standard Committee in which the essential characteristics of the 'added devices' that are to be added on top of noise reducing devices are described. The sound diffraction of the added devices can be determined by performing the sound pressure level measurements at different reference points near the top edge of the noise reducing device with and without added device installed on its top. Also, computing the difference between the mean values with and without added devices could yield efficiency of added devices. The methods described in the standard can be performed in-situ and also on the samples which are prebuilt for the testing according to the methods of the standard.

3.6 Utilizing waste materials

The Central Pollution Control Board (CPCB) Report says that around 30,670 tonnes per day of solid waste were generated in the seven major cities of India in 2011 [38]. In India, only 6% to 7% of solid waste is composted by natural means and the rest is landfilled, resulting in land pollution [39]. Combustion of coal gives waste products constituting of coal fly ash (CFA), coal bottom ash (CBA) and boiler slag, which leads to the greenhouse effect and global warming. CBA is an unburnt agglomerated mass in the coal furnace. The total ash comprises 25% of bottom ash, which could be used efficiently [40]. CBA can be used as a replacement for sand or gravels in concrete as they are getting depleted gradually. Inhalation of such products causes humans to develop various lung diseases [41]. Still, the utilization of CFA in India is more than 38%, whereas it is more than 70% in the developed countries [42]. Adoption of the appropriate procedure for the utilization of these wastes is needed as a study carried out by Arenas et al. [43] which provided a dual advantage to the society. The study revolved around the use of bottom ash (which is the by-product of combustion), instead of gravels, to mix with concrete for the construction of sound absorbent noise barrier. Further, to make the product acoustically effective; the grain particle size of bottom ash, the thickness of the panel, and the combination of different layers with different particle size have been studied. Also, the environmental effect of these barriers was analysed, which yielded a positive result that asserted the material used for constructing the barriers to have no environmental risk.

Further, to improve attenuation, a new eco-friendly approach of introducing a sound absorbing layer in the concrete noise barrier was adopted in Croatia. The raw material for the absorbing layer named RUCONBAR (Rubberised Concrete Noise Barrier) was proposed and developed, which was both environment-friendly and noise absorbing. It consisted of rubber granules from recycled waste tyres (Figure 4). Results indicated that RUCONBAR yielded sound absorption of 6 dB(A) which was more than expanded clay and was not far from the range of wood-concrete barrier, and it was categorized in the A2 class of sound absorption [44]. Later, to determine the environmental impact of the new noise barrier built from RUCONBAR, a Life Cycle Analysis (LCA) was carried out. Results of LCA concluded that RUCONBAR showed lower environmental impact in comparison to noise barriers containing wood-fibre and expanded clay [45].

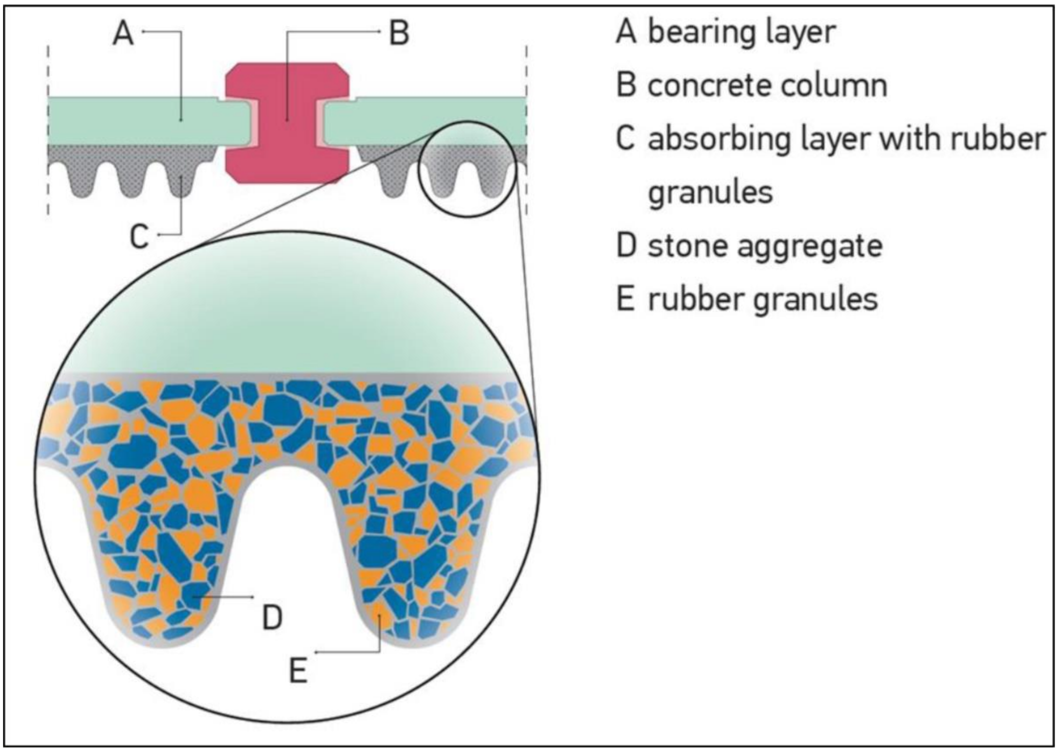

Figure 4. Elements of RUCONBAR [38]

Another study focussed on the effectiveness of a mixture of the shredded palm tree and dampened topsoil in the construction of a noise barrier. This study yielded a dual environmental advantage of recycling of pruning waste, thus utilizing an environment-friendly material for the creation of the noise barrier and noise reduction. The insertion losses of noise barriers of different compositions of a mixture of tree and soil were measured. The most effective sample composition was found to be the one which constituted a mixture of half soil and half chippings and no water. This sample could exhibit overall soundproofing of more than 23 dB(A) [46]. But one of the shortcomings of the barrier made from this material is the long-term performance of the proposed barrier cannot be predicted as the soil may get eroded or the leaves may get degraded.

Fibrous materials have always been incorporated with inbuilt sound absorbing properties. As a result, the polyester fibre was used in the manufacturing of the acoustic absorbent. But polyester in its pure chip form, as obtained from petroleum, became an expensive commodity due to the decrease in petroleum resources and the increase in the prices of petrol. On the other hand, a recent report by CPCB shows that there has been a statistical hike in the tonnes of plastic generated per annum [47] resulting to a need for searching a way to dispose of this waste by utilizing it and hence choose a path which leads to sustainable development. Therefore, a suitable alternative for polyester fibre named “polyester wool” was obtained by the recycling of plastic bottles by Del Rey et al. [48]. Its acoustic properties were found the same as compared to the polyester fibre.

3.7 Sonic crystal noise barriers

Barriers made up of sonic crystals are gaining potential attention due to their competent use in reduction of noise. Certain research has also been carried out to investigate their performance when experimented at different frequency ranges and using various materials for their construction. Lagarrigue et al. [49] studied the acoustic transmission coefficient of resonant triangular sonic crystal made of bamboo rods. The efficiency of the bamboo rod sonic crystal in the audible frequency range was determined by using plane wave expansion method. The properties of the sonic crystal were improved by drilling the bamboo rods which transformed them into stacks of Helmholtz resonators. All the performed experiments were validated with multiple scattering theory algorithms.

Another study on sonic crystal barriers was done by Morandi et al. [50]. He studied sound insulation and reflection properties of 3 x 3m sonic crystal noise barriers that were installed in laboratory of university of Bologna. Sound insulation and reflection properties of sonic crystals were performed by executing free field measurements. Diffuse field measurements were also performed for the sake of comparison. Sound insulation was measured for normal and diffuse incidence and it was found that there was much difference in results of both methods. The results of sound attenuation and reflection were compared with the attenuation predicted by finite size FE model. Comparison of sonic crystal barrier with the common barriers shows better performance of sonic crystal barriers.

Sanchez-Dehesa et al. [51] experimented sonic crystals as noise barriers which were constructed using rubber crumb. Rubber crumb was obtained by recycling used car tyres and were filled into the hollow and perforated metallic cylinders. Three rows of cylinders arranged in a square lattice constituted the barrier. A model was proposed which is based on the theory of multiple scattering in which three different type of cylinders rigid, porous and porous shells with rigid core were used as sonic crystals. Results have shown that three rows of cylinders are sufficient in obtaining the desired bandgaps in the transmittance and reflectance spectra. Also the use of rubber crumb in barriers yielded enhanced insertion loss.

3.8 Cost analysis

Besides the noise reduction capability of a barrier, its cost-effectiveness and life cycle cost analysis (LCCA) is also a significant factor and should be evaluated before implementation. The life cycle cost (LCC) is often ignored, due to insufficient knowledge about barrier maintenance as limited research work is available on this background. The most frequent maintenance measure for road barriers is damage repair, mainly caused by vehicle collisions, as well as changes in weather, such as flood, rain, acid rain, and snow also have a negative impact on the noise barrier. Therefore, conducting an economic feasibility analysis of noise barrier materials is one of the primary steps essential to identify its long-term efficiency to ensure trouble-free performance with no apparent change in barrier insertion loss. Long term performance and durability of noise barrier regards both acoustic and non-acoustic properties and depends on several factors as described in EN 14389-1:2015 and EN 14389-2:2015. These standards guidance methods mention procedures for assessing long term performance of barriers [52,53].

Consequently, a cost analysis of different noise barriers has been carried out with the help of an online tool "Noise Barrier Cost Calculator." In this tool, the barriers are divided into four main categories, namely safety barrier, wall, bund, and wall on top of the bund. The safety barrier is of concrete type (SBC). Wall is of three kinds, i.e., acrylic wall (WA), concrete wall (WC) and timber wall (WT). Then bunds are further classified into four types: Non-Structural Recycled Earth (NSRE), Non-Structural Imported Earth (NSIE), Structural Recycled Earth (SRE), and Structural Imported Earth (SIE). Similarly, the wall on top of bund are divided into NSRE, NSIE, SRE, SIE bund type and acrylic (A), concrete (C), and timber (T) wall type. Inputs such as barrier material, barrier height, bund slope, wall height (in case of a wall on top of bund) were fed in the online tool, and the respective costs were calculated. The barrier height of 3 m has been considered for evaluation except for SBC. Based on the price per linear meter of each barrier a comparative graph is plotted as shown in Figure 5.

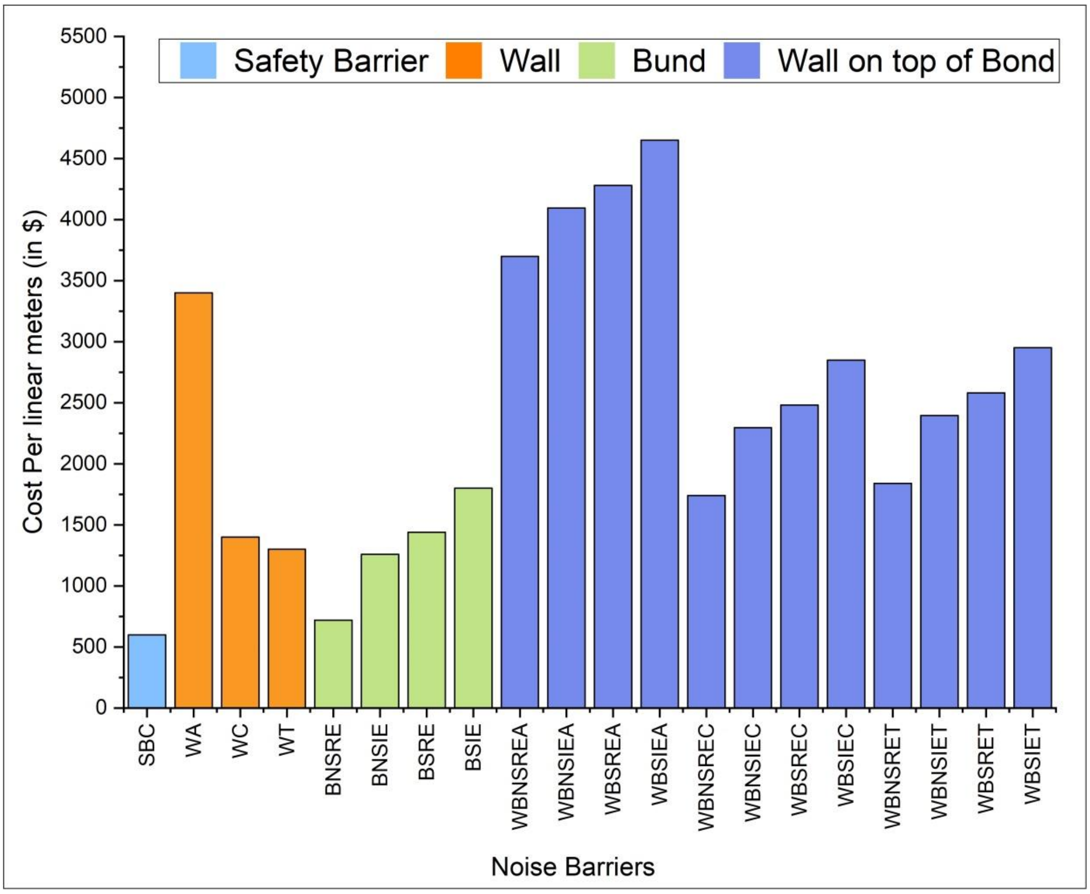

Figure 5. Comparison of different noise barriers according to their costs per linear meters

From the graph, it can be concluded that SBC with an estimated height of 0.8 m to 1.1 m has the least cost per linear meter of $600. On the other hand, acrylic barriers of all types are a bit more expensive than concrete and timber type with SIEA being the most expensive with cost per linear meter of $4095. The critical observation with this study is that our cost analysis conclusions are confirming with the study conducted by Morgan et al. [26] on life cycle cost (LCC) of various noise barrier materials considering the service life and construction cost which is summarised in Table 1 and Table 2.

Table 1. Estimated noise barrier service life [25]

Material	Service life (Years)
Earth berm	50+
Precast concrete, full-height panels with monolithic posts	50
Precast/prestressed concrete cantilever	50
Precast/prestressed concrete stacked panels[a]	50
Fanwall	50
Carsonite	50
Durisol	25
Noishield steel[b]	25
Noishield aluminum	25
Glue-laminated wood	25
Tropical hardwood and softwood post-and-panel	25

[a]Stacked panels (similar to the Soundcore barrier) have not been built in Illinois to date.

[b]Estimated service life for Noishield steel is based on redesigned panels used successfully on projects outside Illinois.

Table 2. Estimated Noise Barrier life cycle cost [25]

Barrier	Estimated ICC [dollars/m^2 (dollars/ft^2)]	Discounted future costs [dollars/m^2 (dollars/ft^2)]	Estimated LCC [dollars/m^2 (dollars/ft^2)]
Earth berm	111 (10.33)	39 (3.60)	150 (13.93)
Precast/prestressed concrete stacked panels, steel posts	212 (19.67)	43 (4.03)	255 (23.70)
Precast/prestressed concrete stacked panels, concrete posts	262 (24.33)	28 (2.62)	290 (26.70)
Timber post-and-panel (hardwood or softwood)	180 (16.70)	122 (11.35)	302 (28.05)
Precast/restressed cantilever	291 (27.00)	30 (2.80)	321 (29.80)
Carsonite	273 (25.33)	50 (4.65)	323 (29.98)
Precast concrete, full height panels, monolithic posts	305 (28.33)	28(2.62)	333 (30.95)
Glue-laminated wood	197 (18.33)	145 (13.48)	342 (31.81)

Durisol	212 (19.67)	152 (14.14)	364 (33.81)
Noishield steel	298 (27.67)	131 (12.19)	429 (39.86)
Noishield aluminum	377 (35.00)	163 (15.15)	540 (50.15)

Vegetation belts can be cost-effective, but they provide less attenuation as compared to other barriers, and their noise reduction depends upon the species of plants available, and the density and depth of the species. Cost analysis and estimation of the service life of vegetation belt as a noise barrier is typically a complex process; vegetation required more maintenance during planting seeds to become mature young trees, along with weather change also contributes to increasing the probability of higher percentages of plant kill and increase maintenance cost of planting new seeds. Also, planting of a mature tree is generally expensive and impractical except in some cases. However, earth berm is comparatively cheaper, but due to land pattern dependence, it is not possible to establish in every highway, especially in the Indian subcontinent. Accordingly, concrete barriers of all types are deliberated as the most effective and affordable noise abatement strategy to control road traffic noise.

4. Conclusion

The evaluation based on the critical review of original papers in response to road induced noise impacts leads to the conclusion that the designing of the eco-friendly noise barriers is the dire need as it provides the dual advantage by utilizing waste material and by reducing the noise levels. The use of waste materials and their possible effective utilization in the construction of noise barriers is a sustainable approach which needs to be practiced. If such concepts are given due attention, it will help in economic designing of barrier structures and also somewhat lessen the burden of discarded waste providing their proper management. However, not much supplementary scientific data is available on such noise barriers, but some researchers have contributed to some fruitful innovations demonstrating good noise absorbing characteristics in the conceptual stage which can be proved to be futuristic realization.

Coal bottom ash (CBA) is obtained as a by-product of coal combustion and holds numerous merits of being used as a construction material for the noise barriers. Different researchers have proven these by demonstrating their sustainable use. Also, if cost is concerned CBA is cheaper as it otherwise will be discarded leading to the pollution of environment, thus it can be an economical option. The use of such materials is necessary as it contributes in effective management of wastes which is a major problem of nearly every country.

The recent and previous literature results confirm that the most effective noise barrier, as far as attenuation is concerned, is the concrete noise barrier as it offers the highest attenuation in the range of 5 to 15 dB(A) and also has a long-term service life. On the other hand, vegetation belts may also be seen as an excellent alternative to concrete noise barriers if they are present in sufficient depth and density typically of 100 to 200 feet wide and evergreen to attain noise attenuation of 10 dB(A), which is still a tough battle. Combination of both can be a more effective noise barrier, where vegetation can act as an absorptive material and concrete wall as a barrier. Earth berms may be useful as they excel in the aesthetic impact, but lack in the strength and lifespan.

Noise barriers are proven to give remarkable performance at noise of high frequencies, but at low frequency they seem to be ineffective therefore making barriers workable at low frequencies is a topic of research these days. Active noise control is one such technique which helps improve performance of barriers at low frequencies. Certain researchers have contributed in designing and analysing such technologies and have achieved promising results. Similar role is of using diffusors over the top profile of barriers to improve their efficacy in limited frequency bandwidth. The use of noise reduction devices over the top edge of barriers have been efficacious in improving acoustic characteristics of barrier as compared to using plain top edge barriers. Use of sonic crystals is gaining attention these days due to their active acoustical response. In addition to these they are versatile as they can be constructed using any discarded material by recycling it thus it proves to be economical as well as efficient at the same time.

Apart from these some natural fibres can also be used as sound absorbers viz. jute, sisal, hemp, flax, pineapple, and banana. Along with natural fibres some of the synthetic fibres could also be obtained by recycling plastic, which otherwise cannot be degraded naturally. Nowadays, almost everything is compelled towards an eco-friendly product, considering this; echo-friendly noise barriers are a good initiative. Extensive research and funding need to be stimulated for supporting the development of new feasible and eco-friendly solution to combat the menace of noise pollution. Also, the concerned authorities and responsible organizations should design a set of rules or organize programs to encourage the use of the generated wastes from industries and other households to build sustainable and ecological noise barriers.

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Author's contribution

This manuscript has been contributed by all the author's listed and have mutually agreed for publication.

Compliance with ethical standards

All the authors and co-authors assure that this review article is our original work, conducted according to the existing scientific ethical practices

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We declare that no conflict of interest associated with this publication

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