Efficiency of Installation of Acoustic Structures in Urban Environment

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Abstract. The article reviews publications within the framework of all-Russian conferences devoted to the problems of increasing the efficiency of acoustic screens in the urban environment. The proposed engineering solutions are identified and analyzed. The principles of the most rational placement of acoustic structures in the urban environment are formulated.

Keywords: acoustic panels, anti-diffraction devices, acoustic hoods, noise.

1. Introduction
Noise exposure leads to increased fatigability either of the whole body, or one particular organ (including brain). While working in noisy environment, a person gets more tired faster, and while resting in such an environment, a person’s body cannot fully restore itself. The lack of proper rest causes the body to tense, which, in turn, could lead to organ or body system failure. This is the way, in which noise could influence a vulnerable spot in a person’s body (complaints of discomfort vary among people exposed to noise).

In Russia, the population of major cities is exposed to excessive noise. Noise could be regarded as a byproduct of human activities. Most people may suffer from noise exposure, though lack social activism concerning solving this problem: people do not know what could and (or) should be done to negate the harmful effect of noise.

2. Importance
Today, there is a fair amount of various sound-absorbing installations and other measures, which help decrease noise exposure of residential areas and their inhabitants. However, implementation of designed antinoise solutions may not always ensure the actual noise reduction, because the taken measures are ineffective or difficult to accomplish due to various reasons (high cost, design flaws, less than responsible attitude to construction and so on) [1-5]. Different technical design projects aimed at noise protection (primarily, installation of acoustic panels (AP)) are being implemented in major Russian cities, although their efficiency and esthetics may be initially inadequate or unable to withstand a “challenge” even within a short period.

3. Research objective
A review of publications on AP efficiency (proceedings of conferences on Protection Against Excessive Noise and Vibrations, held in D.F. Ustinov Baltic State Technical University VOENMEH,
Saint Petersburg, 2006-2017) made it clear that there is no shared vision among experts regarding the efficiency of the proposed design concepts aimed at protection against noise (e.g. AP).

It is widely acknowledged that the efficiency effect of an acoustic panel depends on its size, which, in turn, depends on the size of the noise source (NS), and their relative position in respect to the shielded object. When designing an AP, it should be noted that its efficiency would majorly depend on height of the future structure. The tests show that “the effect of height on AP efficiency is nonlinear in nature: the higher the AP, the fewer is the efficiency improvement with further height increase. For example, if the height is increased from 2 to 3 m, the efficiency improves by 4 dBA, whereas, if the AP height is increased from 5 to 6 m, the efficiency only improves by 1 dBA. A significant improvement of shielding efficiency (up to 3-5 dBA) is observed when the AP height is doubled” [1]. However, even the tallest APs (6 m) have no effect on protection of upper floors inhabitants against noise, which means that either the noise sources have to be shielded, or windows of the building fronts, which are exposed to excessive noise, have to be soundproof [6, p. 433; 7-12].

To improve cost-effectiveness of installation of tall APs, and to enhance the efficiency of smaller size APs, a number of researchers claim it possible to arrange various types of additional structures (anti-diffraction devices, AD), which help compensate for part of the AP height (see figure 1) [1, 13-20]. However, their publications contain no record of efficiency of such additional structures: dimensional ratio (width of construction and AP height) and physical dimensions are not provided. There are no layouts of relative positioning of an AP and a noise source, or information on a reference point for calculations or tests. In the work of T.E. Klyupa, the author attempted to determine AD efficiency in practice [19]. However, structures of different height (AP h=4 m and AP+AD h=4.5 m) were compared in the research. There is no data on the efficiency of a 4.5 m AP without an AD, and no references to theoretical description of the stated approaches, on which AD performance is based (impedance increase on the free edge and diffraction angle increase). Consequently, the issue of AD utilization efficiency remains open.

| № | Basic operating principles | Structural layout | Notes | Name | Symbolic diagram | Additional efficiency, dBA |
|---|---------------------------|-------------------|-------|------|------------------|--------------------------|
| 1 | Diffraction angle increase | ![Diagram](image1) | Through different arrangement of shelves in various combinations | L-shaped | ![L-shaped](image2) | 1.5-2 |
| 2 | Impedance increase on a free edge | ![Diagram](image3) | a) Through sound absorption, b) Through modification of a free edge profile | Arrow-shaped | ![Arrow-shaped](image4) | 0.8-5 |
| 3 | Use of interference effect in resonators | ![Diagram](image5) | Helmholz resonators, etc. | T-shaped | ![T-shaped](image6) | 3-4 |
| 4 | Combined | ![Diagram](image7) | Application of devices, which provide sound absorption, diffraction angle increase, resonance absorption | Y-shaped | ![Y-shaped](image8) | 4.5 |
|   |   |   |   | X-shaped | ![X-shaped](image9) | 4.5-5.5 |
|   |   |   |   | U-shaped | ![U-shaped](image10) | 3.5-4.5 |
|   |   |   |   | Broken | ![Broken](image11) | 1-2 |

**Figure 1.** Additional Acoustic Efficiency of APs of Different Shapes Compared with Straight AP without Additional Structures on the Free Edge [15].

### 4. Theoretical Part

A “panel” could mean any obstruction on the sound propagation path. In urban environment, a role of such an obstruction could be played by walls made of various materials (concrete, metal, wood, stone, plastic, glass and so on) that are erected intentionally, including walls of buildings and constructions, or by natural or man-made terrain (earthworks, banks, hills, cut slopes, ravines, etc.), or a combination of both [6, p. 425; 21-22]. Main function of a panel is to prevent noise propagation into the protected area. Considering diffraction and sizes of audible sound waves (17 m < λ < 17 mm), the AP efficiency
depends on its physical dimensions, soundproofness (acoustic transitivity), and spatial relationship between a noise source, AP and reference point (protected area).

The principle of AP performance is widely known. It is based on the reflection effect (rereflection) of the acoustically hard surface, the absorption effect of the acoustically soft surface, and the scattering effect of the contoured surface [1, 10-11, 15, 23-30]. When giving grounds for efficiency of AD application, the authors of researches should first provide a functional description of the anti-diffraction device, mainly, how it succeeds to manage one of the fundamental properties of a wave – diffraction.

Efficiency of AD structure geometry is yet to be studied further. Calculation methods that are being developed should be described theoretically and justified by proper experimental measurement data. Today, the authors of this paper believe, numerous AD structures proposed for application only have an ornamental function. Any AD structure operates as a wide screen. This means that a narrow AP (compared to a wavelength, \( \lambda \)), which has a broadening atop (AD, shape is irrelevant), imitates a gain in its geometric width, forcing a sound wave to undergo double diffraction from the sides of a panel resulting in additional noise reduction. A similar approach is used for estimation of shielding effect of buildings, depth shapes, earth banks, slopes, hollows, etc. (see figure 2). Sound-absorbing linings of the AD intended to reduce diffracted noise are useless, unless their design is based on Helmholtz resonators. It is understood that sound absorption properties of a material are most effective at sound incidence onto the front surface of the sound-absorbing material. When a sound wave interacts with the AD, especially cylindrical in form, planes of the sound beams and sound-absorbing surface may be considered parallel. Therefore, sound-absorbing effect should be considered null [3, p. 320].

![Figure 2](image)

**Figure 2.** Noise Reduction at Double (1-2) and Single (3-4) Sound Wave Diffraction. 1 – building; 2 – earth bank; 3 – terrace; 4 – hollow road [6, p. 435].

### 5. Practical relevance

If no special measures are taken for acoustic suppression, residential development should be far removed from a traffic way (at least 150 m from expressways and truck routes) [6, p. 205]. Acoustic comfort of people living in close proximity to residential construction sites and main transport routes could be ensured through erection of antinoise buildings, which could be used as powerful acoustic panels. Reduction of noise in the acoustic shadow of buildings reaches up to 25 dBA. Taking into account that multi-storied buildings are frequently erected under modern residential development projects, their shielding efficiency may reach an even higher level [31]. Though it should be mentioned that, just like sound-reducing walls, their efficiency depends on length, soundproofness, and height. Drive-throughs into yards and spacings of buildings reduce sound insulation letting noise reach residential areas. Sometimes, due to rereflection of sound waves, noise level may increase beyond acceptable in the rooms of neighboring buildings located deep in a residential area. To prevent soundproofing of antinoise buildings from decreasing, these buildings should be as long as possible. In case the buildings are erected on constricted spaces within existing development, either they should abut neighboring buildings, or APs of required height should be designed (see figure 3). To lower diffraction on end walls, it would be rational to design a U-shaped noise-protective structure. To limit noise propagation through drive-throughs, A.V. Kolmakov recommends designing them as complex labyrinths with sound-absorbing facing, or plan a driveway into a yard through an underground car park [32-33].
Installation of canopies (AD) with larger overhangs (reaching up to the center of a roadway) could help improve the efficiency of acoustic panels (AP) (up to 18 dBA). In this case a noise source could be compared with a sound source placed into an acoustical shell that opens away from the protected object [8, 35]. As an alternative for such kind of AP structures, N.K. Kiryushkina proposes to cover up the roads completely. This would minimize noise emission and eliminate spatial incoherence created by a traffic route [8]. Open road sections are proposed to be fenced off by multi-storied car parks. In this case, APs should be regarded as acoustic hoods (AH).

Today, cycling or walking along highways with heavy traffic is decidedly problematic. Especially bad acoustic environment is found in enclosed pedestrian overpasses due to increased noise coming through entrances into the enclosed area of the overpass [36].

It is conceivable that implementation of an idea proposed by N.K. Kiryushkina could lead to construction of a network of bicycle routes and electronic transportation devices, which would ensure slower yet soundless transportation, in place of covered-up highways. Apart from noise reduction, this could help lessen primary and secondary dust formation (production and volatilization). Then it may be possible that a part of the population would change their means of transportation (by choosing bicycle and individual e-transport (self-balancing scooters, regular scooters, etc.)) and spend more time outside.

6. Conclusion
Installation of APs, especially of tall panels, should conform to requirements for efficiency, ease of maintenance and long-term operation, due to their cost. When defining and comparing cost-performance ratio of projects designed to shield noise sources, all possible noise sources (NS) found in the urban environment should be considered, including those, which may appear over the course of time. Taking into account that major noise sources in the city are motor- and railways, the most beneficial and cost-effective solutions may be those proposed by N.K. Kiryushkina and A.V. Kolmakov. Covering main traffic routes with acoustic hoods and construction of sound-absorbing drive-throughs (gates) could help reduce the size of urban areas exposed to noise pollution.

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