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NOISE CONTROL FOR A BETTER ENVIRONMENT

Evaluation of the effectiveness of control sources' interval on active noise control performance

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ABSTRACT

Amongst many important factors that affect the performance of active noise barrier, namely, the location of error microphones, and secondary sources, the intervals of adjacent error microphones and secondary sources, etc. this study focused on investigate the effect of secondary sources' interval when they minimized the squared pressure at a set of 15 receivers located in the shadow zone of an infinite barrier. Three different positions around the top edge of barrier considered for secondary sources and best position which achieve the most reduction is selected. Also, the effect of ground reflections on the optimal secondary sources' interval is investigated.

Keywords: Noise Barrier, Reduction, optimization
I-INCE Classification of Subject Number: 38

1. INTRODUCTION

The use of barriers between noise sources and receivers is the widespread solution to avoid the direct acoustic pressure arrive at receivers [1]. Plenty of researches studied different methods to improve the performance of the noise barrier to reduce noise as much as possible. For instance, many of them investigated the effect of barriers shape, dimensions, and thickness on achieved reduction at receivers' area.[2–4]. These studies reported that the barriers are not able to mitigate the low-frequency noises but for compensating this weakness barriers should be high enough to obstacle long noise wavelength. This solution is technically difficult and expensive to use in a real situation, and they have also some disadvantages such as visual blocking.

Active noise control (ANC) is a method to improve the performance of barriers. Many investigations have conducted to evaluate and explain the performance of ANC when added to the barriers [5–11]. There are significant factors such as the location of error microphones and control sources, the distance between adjacent control sources, and the effect of ground reflection that play a key role to increase the efficiency of active noise barrier (ANB).

The objective of this study is to find the maximum distance between adjacent error microphones and control sources when the active control achieves maximum noise reduction in shadow zone of the barrier for narrowband sounds in the range of 100–500

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Hz. Furthermore, the effect of the ground reflection on the performance of active control has been studied for both hard and absorptive ground.

Previous studies worked on optimization of intervals between error microphones [5], but there are few studies investigate the effect of distance between adjacent control sources when they minimize the acoustic pressures in interested area. This research found the optimized distance between sources in different frequencies. The best position for control sources, also detected when the distance is optimized.

2. METHODOLOGY

Figure (1) demonstrates the different zones around a barrier when noise source and receiver located at both sides of the barrier. Lines $\theta = \theta_s - \pi$ and $\theta = 3\pi - \theta_s$ divided the field into three regions. In region I, diffracted waves are the only sound waves pass from the barrier and arrive at the receiver. In region II in addition to diffracted waves, the noise source direct sound arrives at the receiver, and for those receivers located in region III total pressure is the summation of direct, reflected and diffracted pressures. [1]

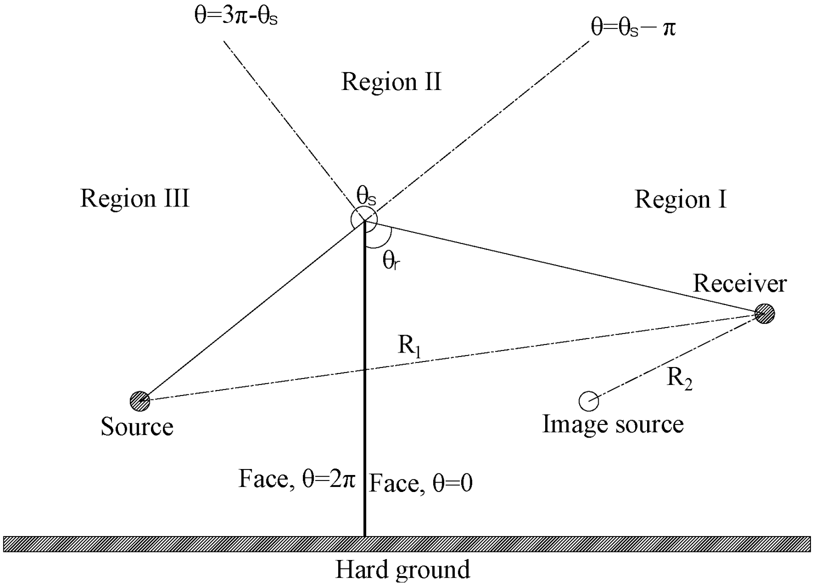


Figure (1): schematic diagram for the diffraction wave

There are several methods to model the edge diffraction, but in this study, an analytical model employed due to its low computation requirements and accuracy. The MacDonald analytical model, which is the developed model of Sommerfeld for more general sound diffraction used to compute edge diffractions.

Equation (1 a-c) present direct, reflected and diffracted acoustic pressure arrive at receivers from sources, respectively.

$$P_d = \frac{-ik\rho\ c}{4\pi} q_0 \frac{e^{ikR_1}}{R_1} \tag{1,a}$$

$$P_r = \frac{-ik\rho\ c}{4\pi} q_0 \frac{e^{ikR_2}}{R_2} \tag{1,b}$$

$$\mathrm{P_D} = \frac{k^2\rho\, c}{4\pi} q_0 [\mathrm{sgn}(\zeta_1) \int_{|\zeta_1|}^{\infty} \frac{\mathrm{H}_1^{(1)}(kR_1 + s^2)}{\sqrt{s^2 + 2kR_1}}\, ds \qquad (1,c)$$

$$+ \mathrm{sgn}(\zeta_2) \int_{|\zeta_2|}^{\infty} \frac{\mathrm{H}_1^{(1)}(kR_2 + s^2)}{\sqrt{s^2 + 2kR_2}}\, ds]$$

The diffracted pressure computed by analytical MacDonald solution, where k is the wave number, q_0 is the source strength and ρ and c are the air density and the sound speed in air, respectively. $\mathrm{H}_1^{(1)}(\,)$ is the Hankel function of the first kind, R_1 and R_2 are the distances from source and its barrier image to the receiver, respectively. s is the variable of the contour integral and the limits of the two contour integrals in equation (1-c) are determined according to

$$\zeta_1 = \mathrm{sgn}(|\theta_s - \theta_r| - \pi)\sqrt{\mathrm{k}(R' - R_1)} \qquad (2,a)$$

$$\zeta_2 = \mathrm{sgn}(\theta_s + \theta_r - \pi)\sqrt{\mathrm{k}(R' - R_2)} \qquad (2,b)$$

where sgn()is the sign function, and θ_s and θ_r are the source and receiver angles respectively according to Figure 1, and R' is the shortest path from source to receiver through the edge.

2.1 Minimization of summation of squared pressure at error microphones

In this approach, the far field noise reduced by introducing a multiplicity of secondary sources whose complex strength are adjusted to minimize the squared pressure at error microphones. Considering "*M*" error microphones, and "*N*" secondary sources, the vector $\boldsymbol{P_{tot}}$ shows the total acoustic pressure obtain in the position of error microphones due to primary and secondary sources, equation [12].

$$\boldsymbol{P_{tot}} = \boldsymbol{Z}_P q_P + \boldsymbol{Z}_s \boldsymbol{q}_s \qquad (3)$$

where $\boldsymbol{Z}_P$ is the vector of primary source pressure with the strength of q_P at receivers, $\boldsymbol{Z}_s$ is an *M*×*N* matrix, and $\boldsymbol{q}_s$ is the vector of secondary sources' strength. Equations (6, a- 6, c) show them in vector and matrix format.

$$\boldsymbol{Z}_P^T = [P_{P1} \;\; P_{P2} \;\; P_{P3} \cdots P_{PM}\,] \qquad (6,a)$$

$$\boldsymbol{Z}_s = \begin{bmatrix} P_{s11} & P_{s12} & \cdots & P_{s1N} \\ P_{s21} & P_{s22} & \cdots & P_{s2N} \\ & \vdots & & \\ P_{sM1} & P_{sM2} & \cdots & P_{sMN} \end{bmatrix} \qquad (6,b)$$

$$\boldsymbol{q}_s^T = [q_{s1} \quad q_{s2} \quad \cdots \quad q_{sN}] \qquad (6,c)$$

where P_{PM} is the primary source pressure at "*M*"th error microphones, P_{sMN} is the "*N*"th secondary source pressure at "*M*"th error microphones, and *T* shows the transpose of the vector. This study considered the squared pressure at receivers ($\boldsymbol{J}_p$) as a cost function for minimization. Equation (7) shows the squared pressure at error microphones,

$$\boldsymbol{J}_p = \boldsymbol{P}^H\boldsymbol{P} = \boldsymbol{Z}_P^H\boldsymbol{Z}_P + \boldsymbol{Z}_P^H\boldsymbol{Z}_s\boldsymbol{q}_s + \boldsymbol{q}_s^H\boldsymbol{Z}_s^H\boldsymbol{Z}_p + \boldsymbol{q}_s^H\boldsymbol{Z}_s^H\boldsymbol{Z}_s\boldsymbol{q}_s \qquad (7)$$

Equation (7) is a quadratic function of the secondary source strength. The vector of secondary sources’ strength obtains by minimizing this function. Equation (8) demonstrates the vector of secondary sources’ strength,

$$\boldsymbol{q}_{s0} = -(\boldsymbol{Z}_s^H \boldsymbol{Z}_s)^{-1}(\boldsymbol{Z}_s^H \boldsymbol{Z}_p) \tag{8}$$

A thin infinite barrier with completely reflective surfaces considered between a primary source and receivers. The barrier is 2.5 m tall. Figure (2), shows the schematic diagram of barrier and receivers, and three different positions of control sources.

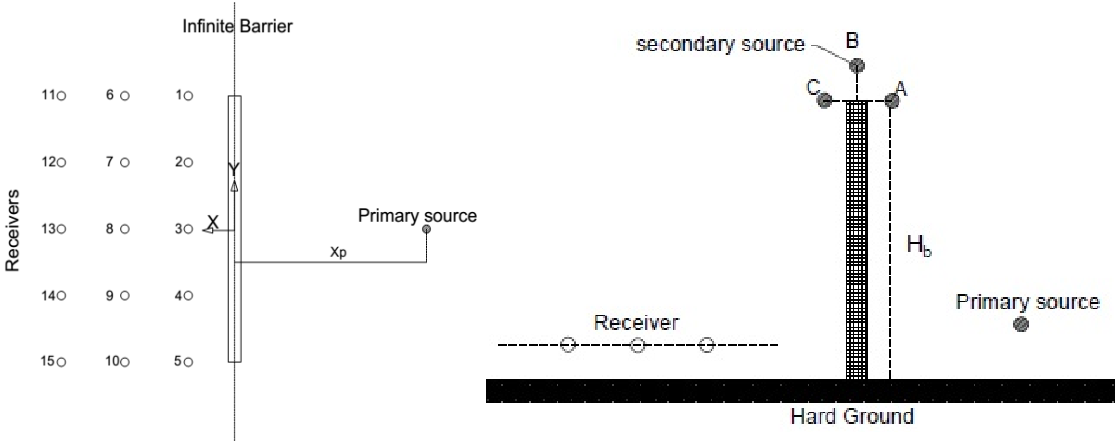


Figure (2): Schematic diagram of an infinite barrier with receivers
(a) Top view, (b) Side view

The set of 15 receivers located in a horizontal plane at the height of Z_r=1.65 m from the ground. The distance between adjacent receivers in Y-direction is 2 m, and are 5 m in X-direction and the barrier is 2 m far from the first row of receivers. The primary source is fixed at the (-7, 0, 0.3) m with the modulus strength of 1 $m^3 s^{-1}$. In order to control the primary source noise, 10 control sources consider in a line arrangement near the edge of barrier in 3 different positions A, B, and C where are 0.5 m away from diffractive edge of barrier. These control sources minimize the summation of squared pressure at 10 error microphones located at the top edge of the barrier. The error microphones and control sources considered along the Y-direction distributed symmetrically with respect to the X-axis.

In this study, the optimized distance between control sources computed when the active control achieves the maximum reduction in sound pressure levels at the group of receivers. The reduction at receivers calculate by Equation 7.

$$Reduction = 10\, log_{10}\left(\frac{\left|\sum_j^M P_{with\ control}\right|^2}{\left|\sum_j^M P_{without\ control}\right|^2}\right) \tag{7}$$

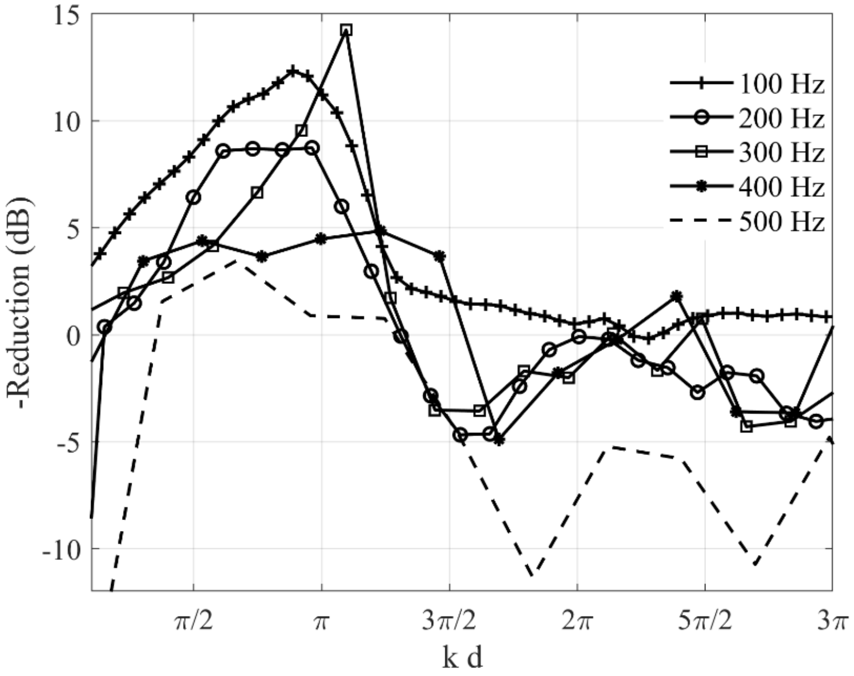
3. RESULT

The effect of three important parameters on the performance of active noise barrier is investigated. These parameters include 1- the location of control sources around the top edge of barrier 2- the interval of control sources, and 3- the soil impedance.

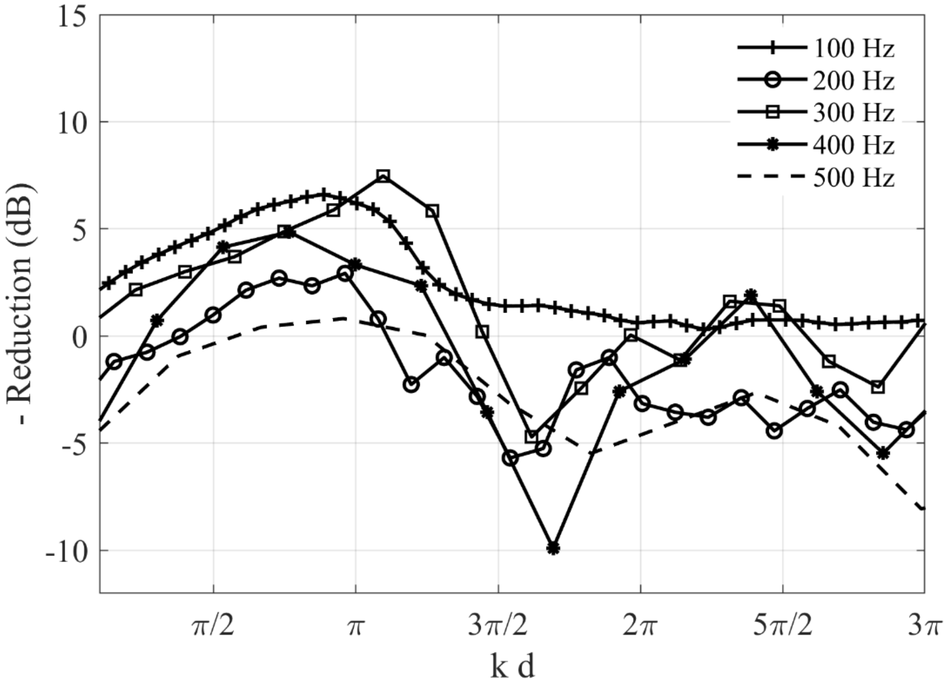
Figure (3) shows the reduction achieved at receivers with the control sources located at three different positions and changing the distance between error microphones from $kd = 0$ to $kd = 3\pi$. Each control source is aligned with the corresponding error microphone.

This figure represents the effect of location of control sources on the performance of active noise barrier. More reduction achieved when the control sources are at position A which indicates that the best position for control sources is in the incident zone and near the diffractive edge.

In addition, this figure displays, the importance of distance between error sensors. As it shows when the number of control sources and error microphones is same the maximum reduction for all frequencies achieved when $kd \cong \pi$, which mean the best distance for error microphones is half of wavelength in each single frequency. This result is independent of the position of control sources.



(a)



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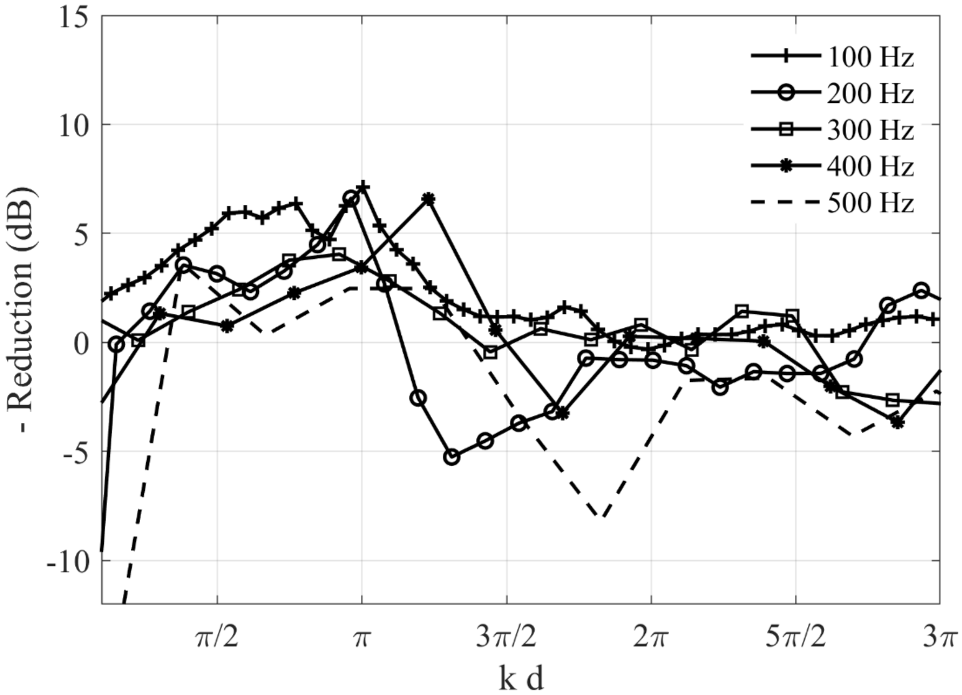
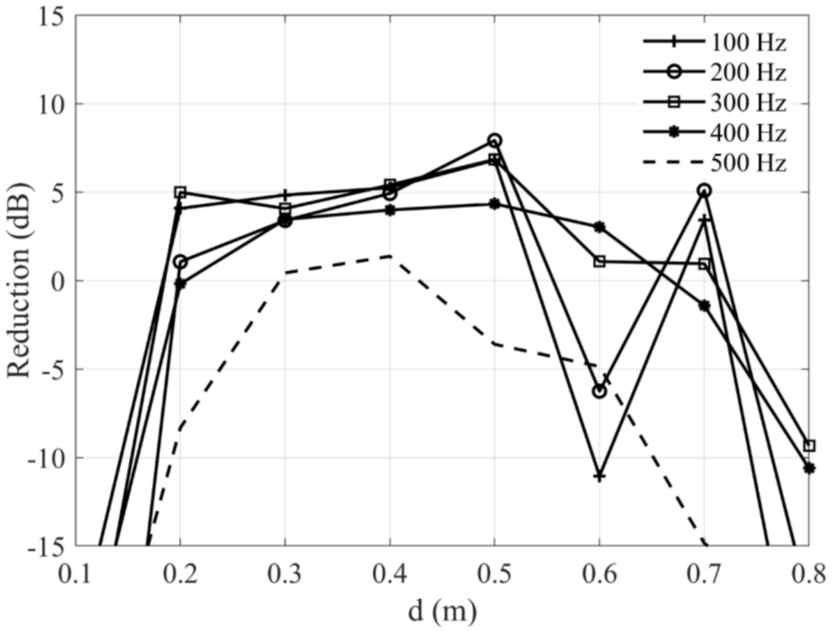


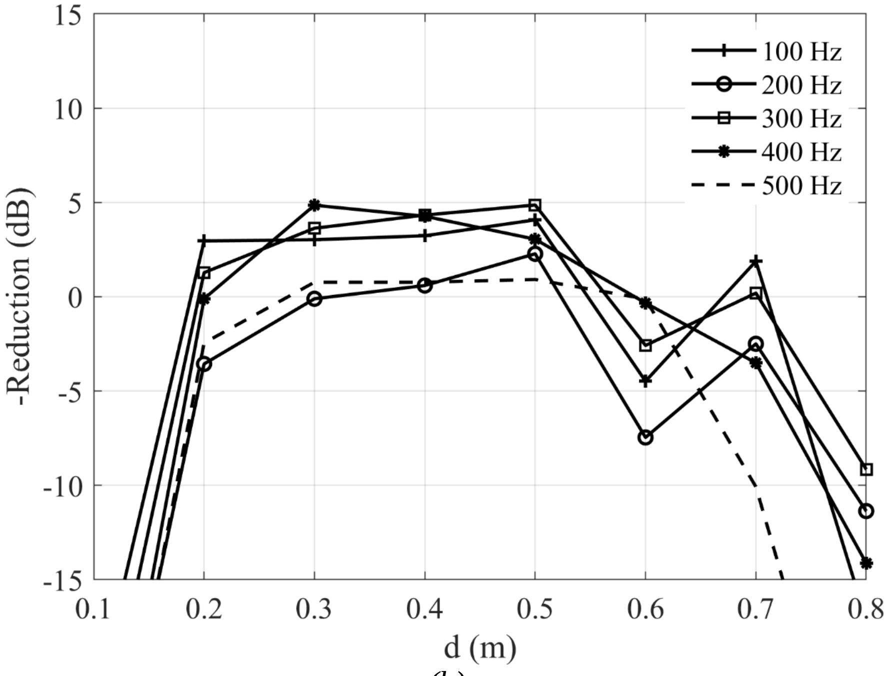
(c)

Figure (3): Reduction at receivers with hard ground, at different control source positions (a)A, (b)B, (c) C

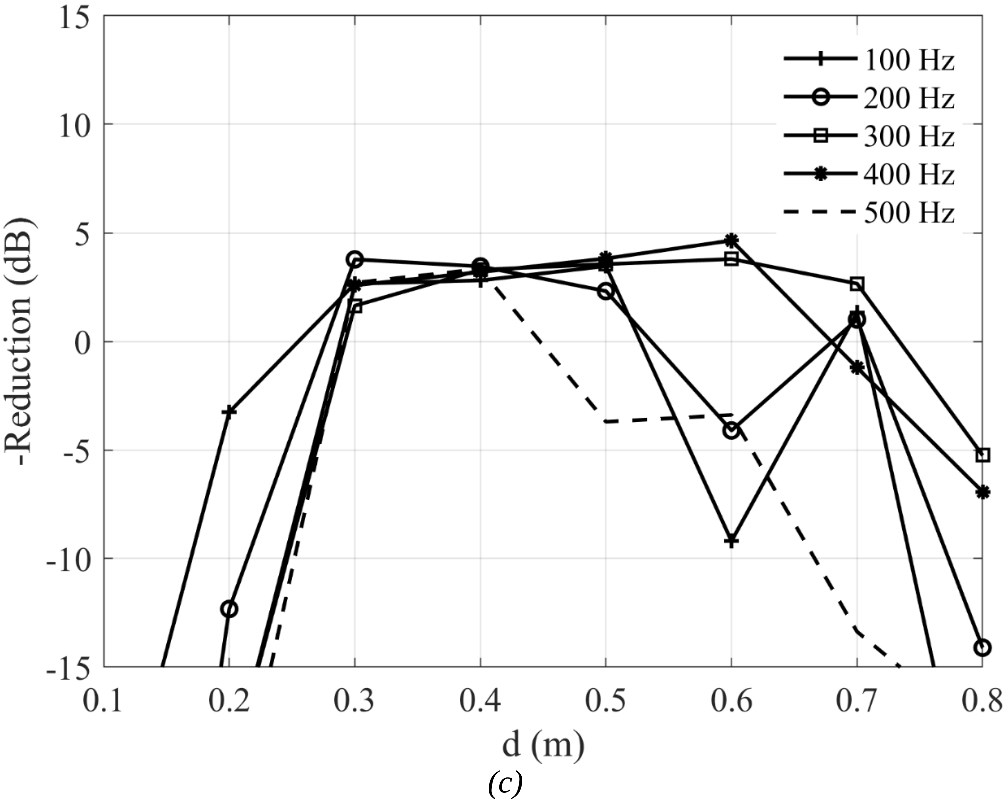
Figure (4) demonstrates the effect of the interval between control sources when the error microphones placed at top edge with a fix distance of 0.35 m, which is half of shortest wavelength in narrowband frequency of 100 Hz to 500 Hz.



(a)



(b)



(c)

Figure (4): Reduction at receivers with hard soil, with different control source interval (a)A, (b)B, (c) C

Figure (4) shows when the distance between error microphones are fixed, the reduction obtained when the distance between control sources is between 0.3 to 0.4 m for the case of control sources at position A, but when they located above the barrier edge, active control mitigate noise when their interval is between 0.3 to 0.6 m, Figure (4,b)), and also when the control sources are at position C, the best interval to reduce noise at the interested area is between 0.3 to 0.4 m. Considering all results of Figure (4), reveal the best distance for control sources should be from 0.3 to 0.4 m, which is close to the value of the distance between error microphones distributed along the edge.

Table 1 compares the reduction at receivers for two cases of hard and absorptive soil. The distance between control sources is 0.35 m which is same as the distance between error microphones. It shows the soil reflection has a destructive effect on the performance of ANB.

Table 1: reduction at receivers with hard and absorptive soil

Frequency (Hz)	Reduction (dB)					
	Hard soil			Absorptive soil		
	A	B	C	A	B	C
100	-5.26	-3.37	-4.71	-5.39	-4.16	-2.37
200	1.42	3.07	-3.6	-4.67	-3.17	-3.26
300	-1.87	-1.26	-1.96	-3.54	2.48	-2.37
400	-4.1	-2.81	-2.52	-2.7	-2.73	-2.4
500	0.88	0.05	-0.71	-2.78	-3.9	-2.3

4. CONCLUSION

This study aimed to find the optimized distance between control sources in order to achieve the maximum attenuation at receivers in the shadow zone of an infinite barrier when they locate in different positions.

Our results show that the optimized distance between adjacent control sources is independent of the position of control sources, and should be approximately the same as half of operating wavelength. Furthermore, the optimal position for control sources is in the incident zone of the barrier.

Finally, considering the pressure reduction in the area of interest, we found the best position for both cases of hard and absorptive soil is the noise incident zone and the best results obtained when the distance between error microphones is less than half of operating wavelength. The results also show the active control works more efficiently when the distance between the control sources is close to the value of distance between error microphones.

5. ACKNOWLDGMENTS

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