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ORIGINAL ARTICLE

Building a Software for Prediction of Noise Propagation in a Complex Condition (Indoor to Outdoor)

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ABSTRACT

The aim of this study was to design and build a software for noise propagation prediction (indoor and from indoor to outdoor spaces) being commonly used in industry. In this regard, firstly a mathematical complex model was created based on existing relationships on noise propagation in indoor spaces and transmission through the walls and propagation in outdoor spaces. To model noise propagation from indoor to outdoor, the function of this model is based on meshing the wall which is effective on outdoor receiver point. By analyzing the required inputs and outputs and designing and documenting the process algorithm, the mathematical model was created and the software was built. In the process of meshing the wall, the software divides the effective wall into 20 parts in length and width and calculations related to sound pressure level on inner wall surface, transmission loss through the wall and leakage from the pores are performed on these meshes. The built software was designed in five forms. Form one for defining hall dimensions and areas of used materials, form two and tree for defining sound sources inside the hall and form five for defining and managing materials were designed. Form four was used for completing required information and monitoring calculation results and software outputs. The software was run with the input data of a gas power plant and outputs were analyzed. The average relative difference between outputs of software (sound pressure levels in given points) and field measurements was below 5%.

KEYWORDS: *Modeling, Noise pollution, Software, Sound propagation, Industrial noise*

INTRODUCTION

Nowadays industrialization and mass production has made various threats to the environment and has caused it to face various harmful factors. One of the factors that has affected daily life during industrialization and advancement of technology is noise. Noise is counted as the most common harmful factor in occupational exposure all over the world [1].

Noise exposure can cause known effects like temporary and permanent hearing loss and unpleasant physiological and mental effects. Noise also has indirect effects on human functions like the work efficiency and productivity reduction and risk of accidents and faults increase due to occurrence of unsafe acts and consequently the the concentration reduction [2-3].

As the environmental impact assessment and urban planning requires the prediction of industry noise propagation in environment, having an efficient tool for such prediction is necessary. In 1976 a research was done in oil industry for specifying noise limits for new plants using the procedure published by OCMA (Oil Companies Materials Association). The procedure defines a calculation method for predicting the noise in neighboring areas due to a plant, which includes curves for deriving the excess attenuation due to ground effects [4].

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In a study in Pennsylvania, USA, about outdoor sound propagation using meteorological and acoustical measurements and a method based on surface layer similarity scaling, atmospheric conditions had an important effect on sound propagation in long distance [5].

A study on sound absorption effects in a rectangular enclosure with the foamed aluminum sheet absorber was done. Throughout the measurement, the foamed aluminum maximized the sound attenuation effect in the interested frequency range [6].

Based on general methodology published in environmental modeling book in 2000 [7], sound pressure level forecasting is of the following form:

1. Determine source power levels Lw.
2. Compute total atmospheric attenuation for a given environment scenario by calculating the individual attenuation components Ki as follows: Geometric spreading, Enclosures, Barriers, Air absorption, Wind effects, Temperature gradient effects, Ground effects, Shielding by vegetation and buildings.
3. Compute the resultant sound pressure level at an environmental point. The complexity of the forecasting program is invariably measured by the number of attenuation components Ki included in the calculation and by the complexity of the algorithms used to determine the components. The simplest of schemes used allows for geometric spreading only without further corrections, but the algorithms are predominantly of 2 types: one based on a theoretical approach and the other on an empirical approach. Use of theory to completely describe the real world is the ultimate objective but we must at present be content with a blend of theory and empirically derived relationships. In the real world we expect that the sound pressure level at a point in the environment is in fact more like Lp=F(Lw,ik) in which all the individual attenuation factors ik together with the source power levels Lw inter-relate in the function F. Some of these inter-relationships have only recently been explained. For example, in the case of barrier attenuation, recent work shows the effect that the ground has on both sides of the barrier. Commercially available programs for noise prediction are still limited in number, notably, ENM produced in Australia and SOUNDPLAN produced in Germany [7].

A research was done about prediction of outdoor sound transmission loss with an artificial neural network [8]. In this research, an artificial neural network was developed for rapid prediction of sound transmission loss (TL) during propagation outdoors. ”The network predicted TL for a no turbulent atmosphere from inputs involving the source/receiver propagation geometry (height range: 0–5 m, horizontal separation distance: 100–900 m), source frequency (range: 20–200 Hz), ground properties, and atmospheric refractive profile characteristics. Only 18% of the cases resulted in RMS errors that were greater than 2 dB “[8].

At the moment there is not any software for predicting noise propagation from indoor to outdoor. Besides, available software for using in industry is too complex. Hence building a simpler software will be helpful in environmental impact assessment and planning.

The aim of this study was to build a software for noise propagation prediction (indoor and from indoor to outdoor spaces). The built software was in Persian language and windows-based and released in autumn 2014.

MATERIALS AND METHODS

To build the software, firstly a mathematical complex model was created based on indoor sound propagation relationships (Sabine model), sound transmission loss through non homogenous walls and sound leakage through pores, and outdoor sound transmission loss. The function of model for indoor sound propagation calculation is based on Sabine model and Equations 1-4 [9]. (Sound sources are considered as point sources and centers of sources are used in model)

$$Lp = Lw + 10Log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right) \qquad \textit{(Equation 1)}$$

Where:
LP= Total Sound Pressure Level in each octave band center frequency (dB)
LW= Sound power level in each octave band center frequency (dB)
Q = Directivity factor
r = Distance from source to receiver (m)
R = Room constant (m^2)

$$R = \frac{S\bar{\alpha}}{1-\bar{\alpha}} \qquad \textit{(Equation 2)}$$

Where:
S = Total surface area (including walls, floor, ceiling and sound sources in m^2)
R = Room constant (m^2)
$\bar{\alpha}$= Hall Average absorption coefficient

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} S_i\alpha_i}{\sum_{i=1}^{n} S_i} \qquad \textit{(Equation 3)}$$

Where:
$\bar{\alpha}$= Hall Average absorption coefficient in octave band center frequency
n: the number of materials in surfaces and sound sources
Si= the corresponding material surface area (m^2)
α_i= the corresponding absorption coefficient in octave band center frequency

(Equation 4)

$$r = \sqrt{(Xr - Xs)^2 + (Yr - Ys)^2 + (Zr - Zs)^2}$$

Where:
Xr, Yr, Zr= receiver coordination
Xs, Ys, Zs= sound source coordination

The hall was considered like actual cube in the determined mathematical model. The mathematical model detects one wall as the most effective wall on receiver point and divides the wall to 20 sections in length and width in order to find the outdoor receiver's sound pressure level. The mentioned division makes 400 meshes. Then, the model calculates the inner surface sound pressure level in octave band center frequencies in each center point of meshes. Surveying octave band center frequencies in this mathematical model have been selected of 125, 250, 500, 1000, 2000 and 4000 Hz. In this model, walls are assumed homogenous and though the area of the pores and the materials used in the walls will be distributed among all the meshes. Then the sound transmission loss will be calculated in each center point of meshes and octave band center frequencies, based on the average transmission loss coefficient (τ) and the relative equations [10]. The model uses Fig.1 to survey the noise attenuation from the transmission loss [11].

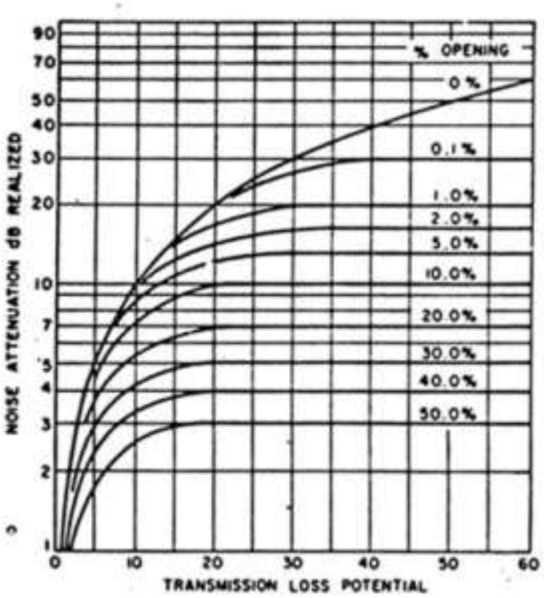

Fig.1. Noise attenuation curves based on transmission loss [11]

In accordance with the curves, the mathematical model calculates the real noise attenuation in each octave band center frequency in all meshes and thus the sound pressure level in meshe's outer surface will be determined in octave band center frequencies. Fig.2 and Table 1 show the mathematical model function on meshes:

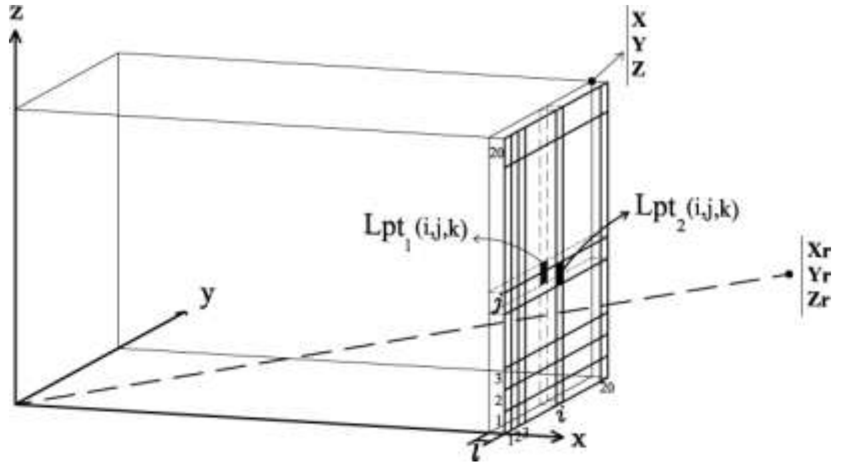

Fig. 2. Meshing the effective wall

Lpt1(i,j,k): Sound pressure level in the center of i-th horizontal and j-th vertical mesh in K-th octave band center frequency on the inner surface of the wall

Lpt2(i,j,k): Sound pressure level in the center of i-th horizontal and j-th vertical mesh in K-th octave band center frequency on the outer surface of the wall

Table 1. K allocation to the octave band center frequency in 3 dimentional array of matematical model related to the wall meshing

k	1	2	3	4	5	6
Frequency (Hz)	125	250	500	1000	2000	4000

In the last stage, based on considering the center point of each mesh as a sound source, the matematical model calculates the sound pressure level in the receiver point using empirical relationships of outdoor sound propagation including distance attenuation, ground absoption effect and atmospheric absorption. Fig.3 shows the relative information about the matematical model function:

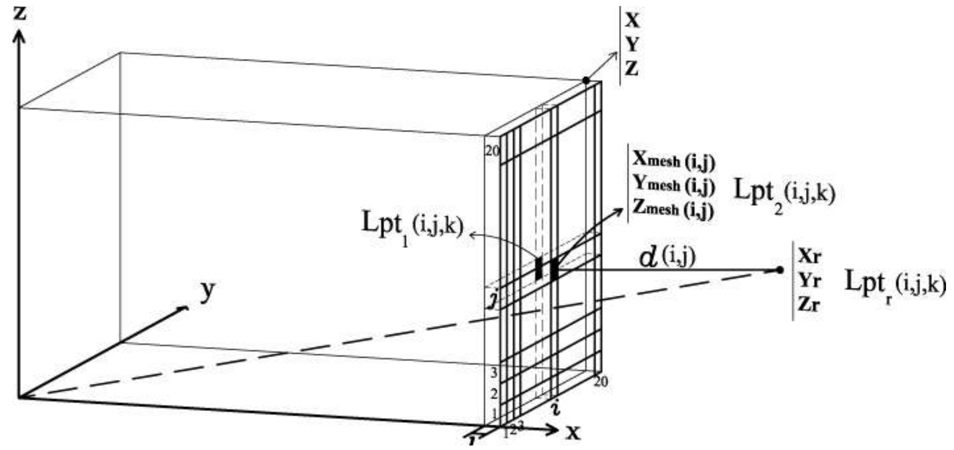

Fig. 3. The effect of the outer surfaceof meshes on the receiver point

A group of inputs and outputs were determined and categorized for software implementation of the mathematical model. Then the user interfaces of the program were designed in five forms and the general flowchat of program algorithm was outlined. Hence, the form one was designed to get information about hall dimensions and its material surface areas. Forms two and tree to get information about the sound sources inside the hall and form five to manage acoustic information of the materials. Form four was designed to get required complementary information and show calculation results and software outputs. Finaly the mathematical model was implemented in calculation sequences and processes and the software was built.

RESULTS

The turbine hall of a power plant was chosen as a real scenario to survey the software function. The hall and its sound sources were not actual rectangular cube. So an estimation was used in hall plan and 3D model (according to Figs. 4 to 7) to be able to input information in the software.

Based on mentioned modeling, hall dimentions were considered as X=160.7m, Y=31.3m and Z=18.2m. The hall floor was made of concrete, the ceiling was made of metal and the walls were made of bricks. On the walls there were 5 different types of metal doors. Doors STD1 were single leaf type with dimentions 1.1m × 2.5m. Doors STD2 were double leaf type with dimentions 1.5m × 2.5m. Doors STD3 were double leaf type with dimentions 2.2m × 2.5m. Doors STD4 were rollup type with dimentions 6m × 6m and doors STD5 were removable type with dimentions 6m × 6m [12]. To simplify calculation of metal and brick areas on each wall and input them in the software, wall views were drawn using estimated plan and 3D model. Figs 8 to 11 show wall views and calculation results of material areas on each wall. Fig.12 shows inputing these information in form 1 of the software. Turbine dimentions were X=6.2m, Y=10.2m and Z=3.9m and generator dimentions were X=2.6m, Y=7.5m and Z=3m [12]. Generators surfaces were made of metal and turbines surfaces were made of stone wool. The sound sources S1 to S8 in Fig.5 (The estimated turbine hall plan), are labled according to Table 2.

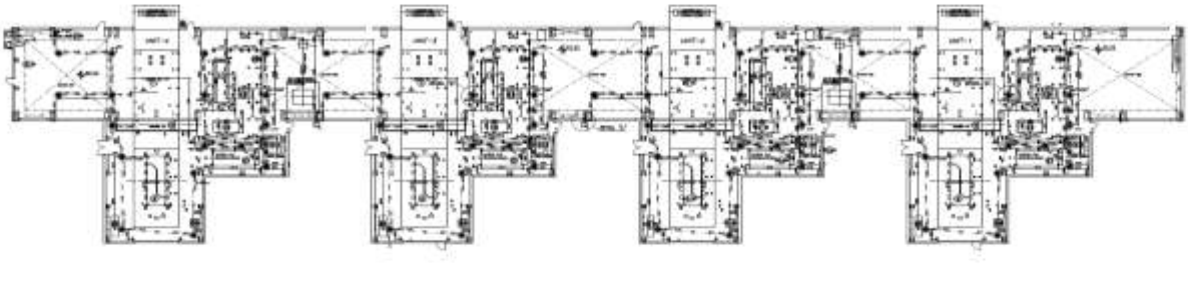

Fig.4. The turbine hall plan of the gas power plant

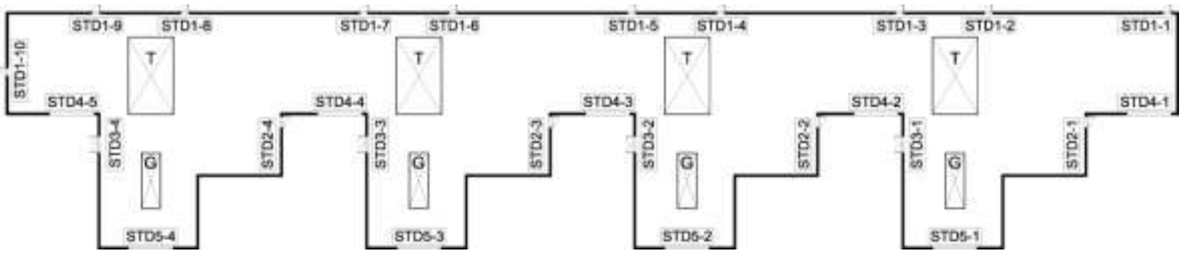

Fig.5. The simplified turbine hall plan of the power plantincluding turbines, generators and doors

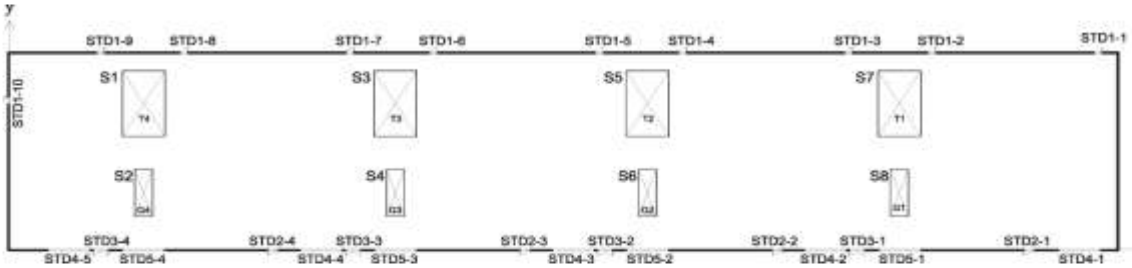

Fig.6. The estimated turbine hall plan of the power plant

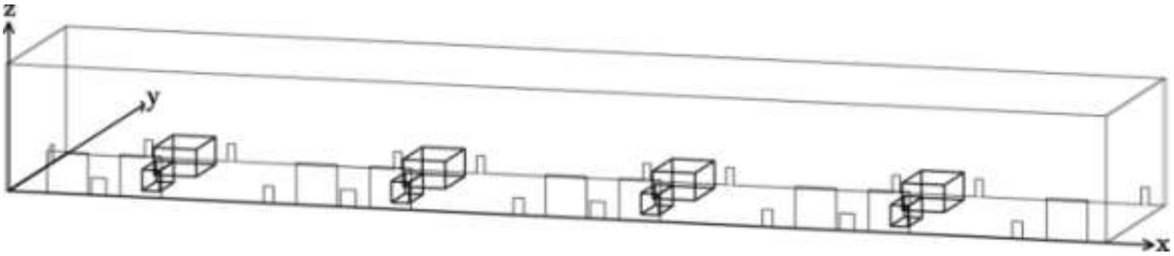

Fig.7. The turbine hall 3D model of the power plant

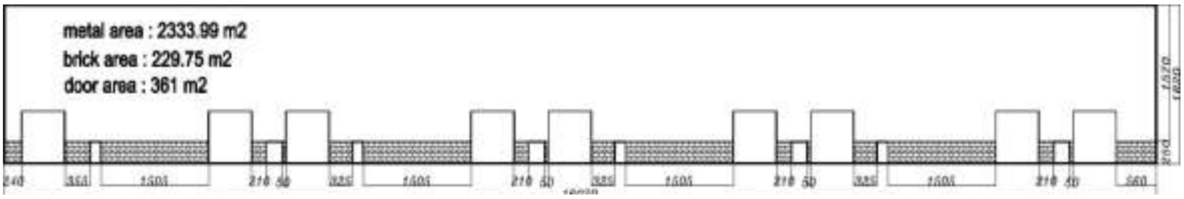

Fig.8. Indoor view of the rear wall in turbine hall reverse plan of the power plant

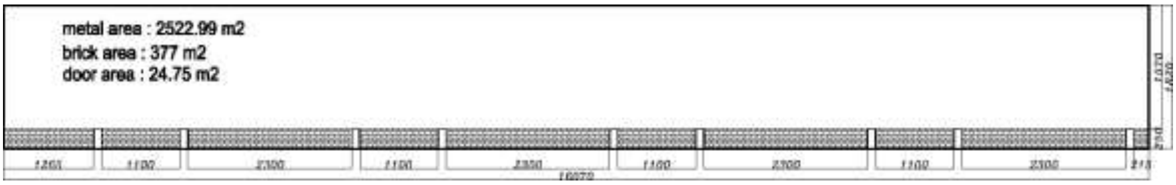

Fig.9. Indoor view of the front wall in turbine hall reverse plan of the power plant

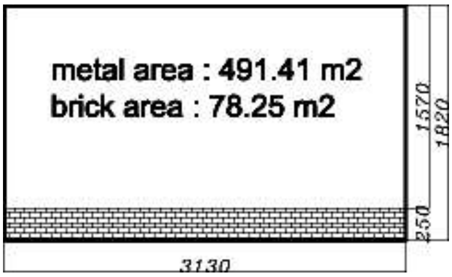

Fig.10. Indoor view of the left wall in turbine hall reverse plan of the power plant

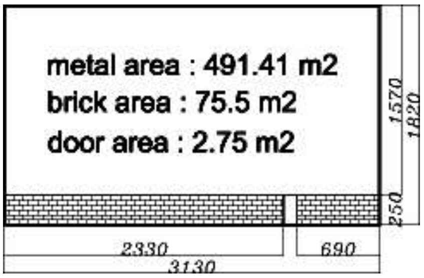

Fig.11. Indoor view of the right wall in turbine hall reverse plan of the power plant

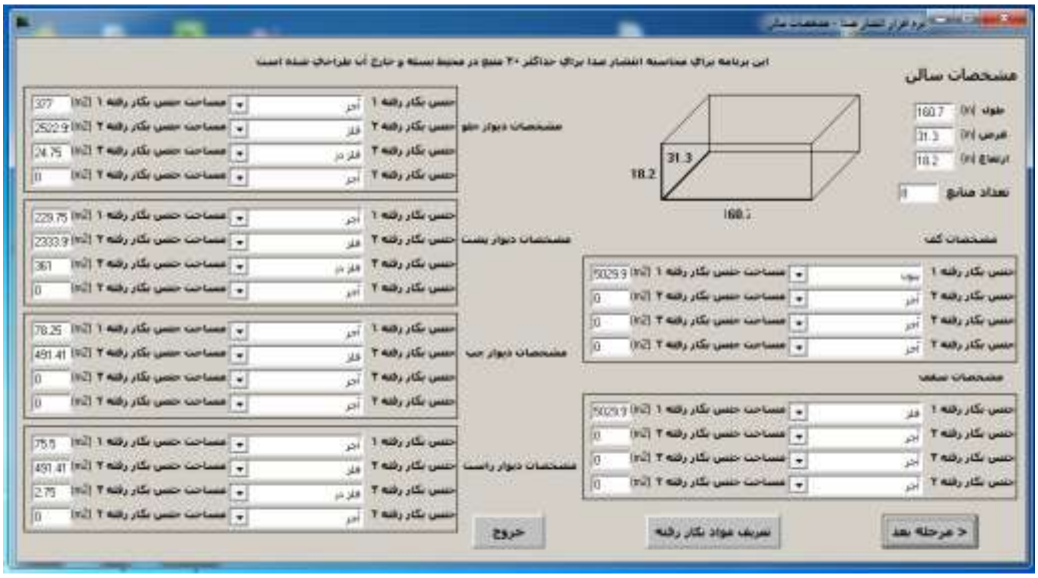

Fig.12. Form 1 – software run with input information of the power plant

Table 2. Sound sources labling in turbine hall of the power plant

S1	S2	S3	S4	S5	S6	S7	S8
Unit 4 turbine	Unit 4 generator	Unit 3 turbine	Unit 3 generator	Unit 2 turbine	Unit 2 generator	Unit 1 turbine	Unit 1 generator

The center of turbines and generators coordinationswere calculated using reverse estimated plan and inputed in form 2 of software. The sound power levels of these sound sources in octave band center frequencies were also estimated using sound pressure lavel field measurements at a distance of 0.5m from sound sources and were inputed in form 2 of software. Note that this sound power level is just an estimation according to the fact that in a reflectvie enclosed space with the room constant less than 50 square meter, the sound pressure level is equal to the sound power lever in distance around 0.3 to 0.5 meter from the source. The more accorate sound power level measuremet should follow the relative standard method.

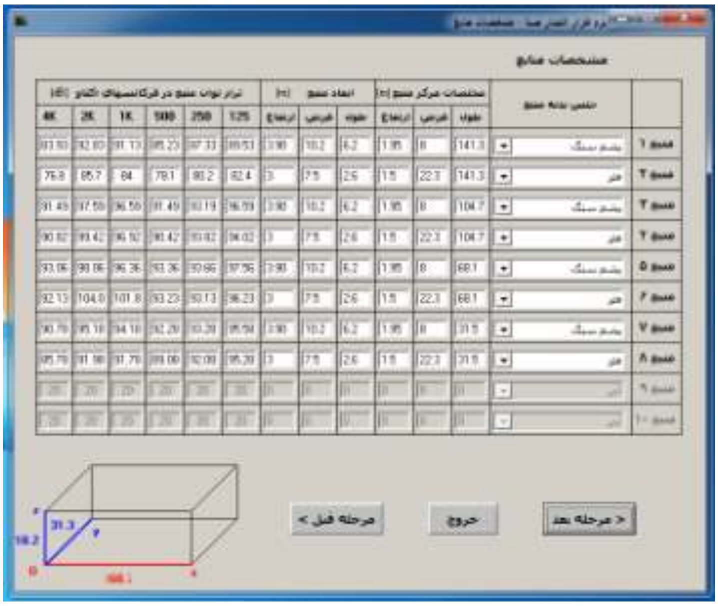

Fig.13. Form 2 – Software run with input information of the power plant

The hall elements thickness were 35 cm for brick walls, 5 cm for metal doors and 1cm for metal walls and ceiling. The atmospheric condition was considered as the temperature of 30 ˚C and humidity of 70%. The ground around the power plant was considered as hard ground. Field measurements were done outside hall in octave band center frequencies at a height of 1.5 m and at a distance of 0.5 m from doors STD1-10, STD2-1, STD2-4, STD3-3, STD3-4, STD4-1 and STD5-3. The center of these doors cordinations were calculated using reverse estimated plan and inputed in form 4 of software. These cordinations are presented in Table 3:

Table 3. Field measurement points cordinations – Turbine hall of the power plant

Measurement points	STD1-10	STD2-1	STD2-4	STD3-3	STD3-4	STD4-1	STD5-3
X(m)	161.2	12.8	122.6	110.9	147.5	5.4	104.7
Y(m)	7.5	31.8	31.8	31.8	31.8	31.8	31.8
Z(m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5

The software outputs were recorded after entering different values in pores area percentage field. Figure 14 shows inputed information in form 4 and software outputs for the door STD1-10 with 20% pores area percentage:


محاسبه تراز معادل فشار در یک نقطه خارج سالن

مشخصات نقطه :
طول : 161.2
عرض : 7.5
ارتفاع : 1.5

ضخامت مواد بکار رفته در دیوار :
ماده ۱ : 35
ماده ۲ : 05
ماده ۳ : 01
ماده ۴ : 0

وضعیت زمین : سخت
وضعیت دما و رطوبت : رطوبت ۷۰٪ ، دما ۲۰
درصد مساحت منافذ دیوار موثر : ۲۰٪

dBC 74.8686
dBA 72.5781

محاسبه تراز معادل فشار در یک نقطه داخل سالن

مشخصات نقطه
طول :
عرض :
ارتفاع :

dBC
dBA

ضریب جذب متوسط سالن در فرکانسهای اکتاو	وضعیت سالن	ثابت اتاق
۱۲۵ : 0.03307	بازتابی	631.493
۲۵۰ : 0.04189	بازتابی	807.239
۵۰۰ : 0.07192	بازتابی	1430.791
1k : 0.07178	بازتابی	1427.807
2k : 0.06863	بازتابی	1360.62
4k : 0.06505	بازتابی	1284.60

Fig.14. Form 4 – software run with input information of the power plant – output point STD1-10

To be able to compare field measurement with software output in each point, measurements in different octave band center frequencies at each point should be combined. The measurements and combination results are presented in Table 4:

Table 4. Field measurements of sound pressure level in outdoor points– Turbine hall of the power plant

Measurement point	SPL (dBC) in octave band center frequencies (Hz)						Lp_{total}(dBC)
	125	250	500	1000	2000	4000	
STD1-10	73.1	59.2	50.7	57.4	61.2	45.1	73.66
STD2-1	75.1	68.5	67.7	63.9	66.8	65.6	77.49
STD2-4	62.8	59.4	52.9	56.4	56.7	47.2	65.94
STD3-3	63.4	58.2	51.9	55.2	56.5	45.1	65.81
STD3-4	63.4	58.2	51.9	55.1	56.5	45.1	65.80
STD4-1	74.8	67.3	64.8	64.5	68.7	54.8	76.91
STD5-3	64.2	59.5	53.2	56.4	56.9	46.5	66.72

The software outputs at the same measurement points were recorded after entering different values in pores area percentage field. The results are presented in Table 5:

Table 5. Software outputs resulted from different values of pores area percentage at the measurement points

Measurement point	The software outputs (dBC)resulted from different values of pores area percentage								Field measurement (dBC)
	0%	0.1%	1%	2%	5%	10%	20%	30%	Lp_{total}
STD1-10	41.23	51.73	61.35	64.38	67.43	71.60	74.86	76.0	73.66
STD2-1	50.68	57.08	65.84	68.84	71.85	75.85	78.87	79.88	77.49
STD2-4	36.22	40.16	48.0	50.92	53.88	57.86	60.86	61.86	65.94
STD3-3	36.51	40.68	48.64	51.57	54.54	58.52	61.53	62.53	65.81
STD3-4	35.54	38.84	46.29	49.18	52.12	56.08	59.08	60.08	65.80
STD4-1	44.26	50.41	59.11	62.1	65.1	69.11	72.13	73.14	76.91
STD5-3	36.68	40.96	48.98	51.91	54.88	58.87	61.87	62.87	66.72

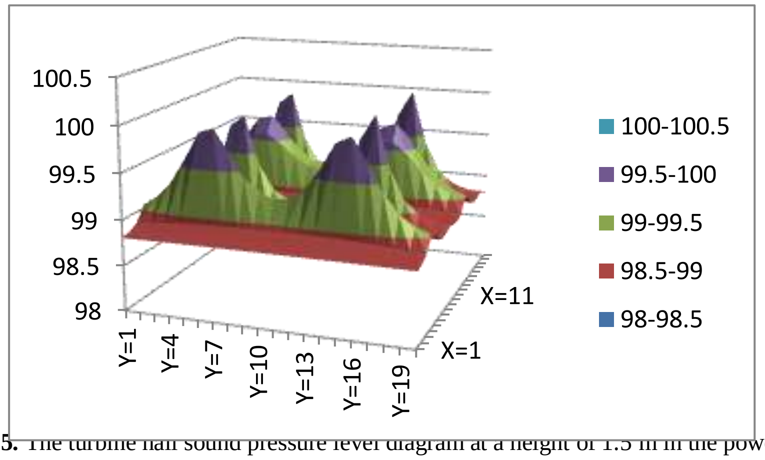

Fig.15. The turbine hall sound pressure level diagram at a height of 1.5 m in the power plant

Surveying Table 5 showed that the closest values to field measurements have been achieved in software outputs at 2 points of the 20% pores area column and 5 points of the 30% pores area column. These points have been selected as the software outputs and are drawn in figure 16 with field measurement curve:

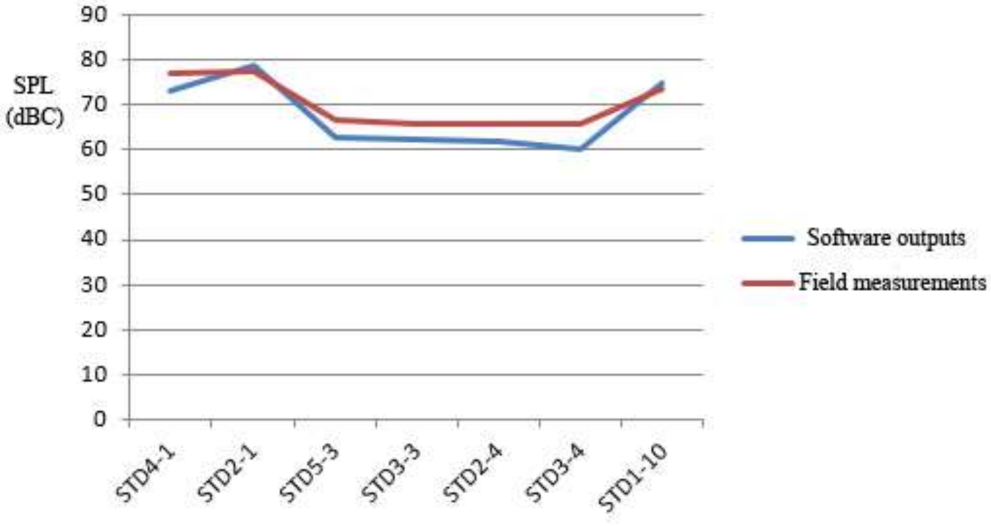

Fig.16. Software output and field measurement in the power plant (dBC)

The difference between software output and field measurement at each point has been calculated and presented in figure 17:

The outputs confidence coefficient is calculated from average ratio of software outputs to field measurements and is presented in figure 18:

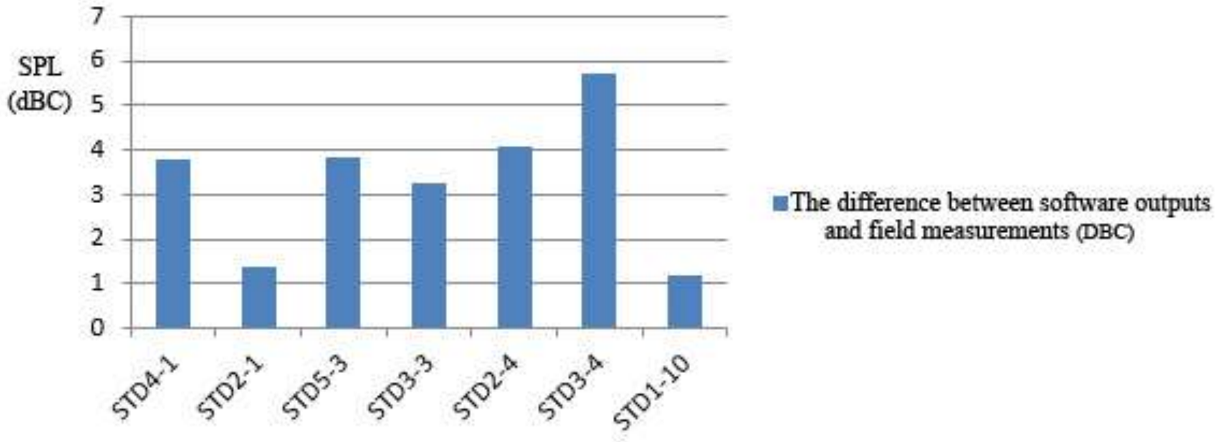

Fig.17. The difference between software outputs and field measurements (dBC)

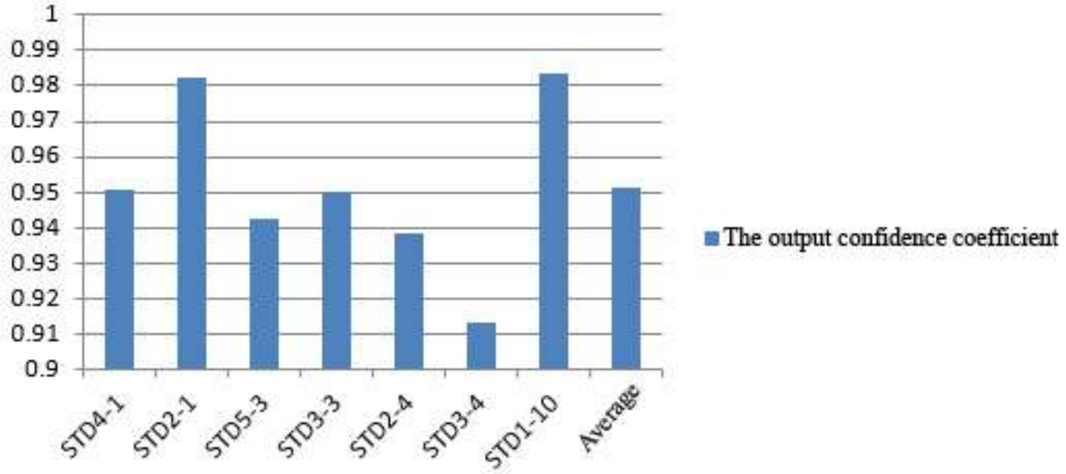

Fig.18. The software outputs confidence coefficient (%)

The calculated value of confidence coefficient was 95.15% and the average relative error between outputs of software and field measurements was 4.85%.

DISCUSSION

Based on the considered tables and figures related to the software outputs in the power plant scenario, in some outdoor points, field measurements are adopted with the 20% pores area curveof the software outputs and in some other pointsare adopted with the 30% pores area curve. In reality, the ratio of wall pores to total area in turbin hall is less than 20% or 30%. The reason foradoptation between 20%-30% pores area curves and field measurements is that the software meshes the walls, and distributes the wall used materials in all the meshes reatively balanced. The sound leakage is also distributed homogenousely through the meshes. In reality, the materials are not distributed homogenousely through the walls and as an example, at thepoints near doors and windows, the transmission loss and sound leakage will be less and more than the calculated ones respectively.

In the power plant, the field measurements have been conducted at a distance of 0.5m from the doors. Hence, the measured data show higher amounts compared with the software calculated one. It means that the measures are more adopted with the software output data in higher sound leakage inputs. To sum up, irregularities and discrepancies occure between the software output and the real measurement-based data near the wall, doors and windows. Because at the discussed points, the porporation between the mesh sound transmission and sound leakage in the software and the real one will be changed. Hence the software shows a higher output accuracy in farther distances from the wall.In the closer distances to the wall, more balanced distribution of the materials in the wall will cause more accurate software outputs.

CONCLUSION

Based on comparison between software outputs and field measurements in the power plant, the built software offers an acceptable estimation of industry's noise propagation in the environment. This estimation can be used by industry managers for locating and designing the industry and for environmental impact assessment of the industry.

By surveying the effect of software inputs variation on outputs, the built software is a powerful tool for industry designers to reduce indoor and outdoor noise propagation cost effectively. Inputs variation in this case can be walls and sound sources surface material, doors and windows sound leakage and vegetation. The software can also be used to survey the correction of indoor and outdoor noise propagation in the existing industries.

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REFERENCES:

1. Haines MM, stansfeld SA, chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children. *Health* 2001;31 (2): 265-277.
2. WHO, Occupational and community noise, World Health Organization, Geneva, 2001; Fact sheet No.258
3. Saeki T, Fujii T, Yamaguchi SH, Harima S. Effects of acoustical noise on annoyance, performance and fatigue during mental memory task. *Applied Acoustics* 2004; 65: 913-921.
4. Marsh K.J., Spesification and Prediction of Noise Levels in Refiners and Petrochemical Plant. *Science Publishers LTD* 1976; 2-13.
5. Nicolas J, Wilson DK, Thomson DW, et al. , Sound Propagation in the Atmospheric Surface Layer. *Institute for Microstructural Sciences* 1993; Vol.40: 325-346.
6. Eung O, Sang-Hun K, Jin-Tai C, et al., Sound Absorption Effects in a Rectangular Enclosure with the Foamed Aluminum Sheet Absorber. *KSME Int J* 1998; 12: 1017-1025.
7. Tonin R. Environmental Noise Modeling, Envinmental Modeling, 2000; 1: 340-351.
8. Mungiole M, Keith WD. Prediction of Outdoor Sound Transmission Loss With an Artificial Neural Network. *Appl Acous* 2006; 67: 324-345.
9. Bell L. Industrial Noise Control: fundamentals and applications, Marcel Dekker-INC, New York, 1994.
10. Barron R. Industrial Noise Control and Acoustics, Marcel Dekker-INC, New York, 2001.
11. Bell L. Industrial Noise Control: fundamentals and applications, Marcel Dekker-INC, New York, 1994.
12. Ekhlas H., Nassiri P., Monazzam M. R., Mansouri N. Modeling and verification of acoustic wave propagation in indoors using Sabine model in turbine hall of a gas power plant. *J Health Saf Work* 2014; 4(1): 73-86.