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Effect of Micro-holes Addition on the Natural Frequency and Mode Shape of Perforated Plates

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ABSTRACT

In this paper, an extensive work on the natural frequency of perforated plate has been made by introducing micro-holes on the plate. The micro-holes, which is known to have a remarkable performance in several applications, were arranged diagonally among the perforated holes in order to make a new combination of micro-macro perforated plate. A 3D geometrical model of the plate was made in the Autodesk Inventor and the Finite Element (FE) simulation was employed to calculate the natural frequency and visualize the mode shape. Four models were made with various micro-holes diameter starting from 0,25, 0,5, 0,75 and 0,9 mm, respectively. The macro holes diameter, however, was kept constant to be 1,5 mm purposely to know the effect of micro holes in particular. The results from the models were then compared to a single perforated plate (PP) for clarification. It is found that the micro holes gives considerable effect to the perforated plate natural frequency. Similar to the author previous findings, the diameter of the micro holes is proportional to the natural frequency reduction.

Keywords:
Natural frequency, perforated plate, microholes, finite element

1. Introduction

Study on plate and perforated plate have been attracted researchers in many ways [1-6]. Despite their ability to become future alternative materials, perforated plate particularly provides several engineering benefits i.e. considerable structural strength and good acoustical performance. More than that, they are also easy to be modified and having aesthetic looks from design perspective.

Researches on the perforated plate (PP) with micro or macro size holes have been extensively conducted by researchers. Chang *et al.*, [7] investigated the sound absoption performance of double-layer perforated plate at low frequency. The perforated plate were placed with large-back cavity depth. It is found that the double-layer performs well as an acoustic absorber at low frequency and it was sensitive to the aperture of perforation and thickness of the plate. Li *et al.*, [8]

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studied the absorption performance of flexible micro-perforated panel with ultra-micro perforations. This study was very insteresting since the author tried to introduce ultra-micro holes on the plate which requires a high end manufacturing process. The best acoustical performance was found for flexible micro-perforated panel made of polyethylene telephthalate (PET). It was also found that the optimal results could be achieved by tuning the plate parameters i.e. hole diameter, perforation ratio, thickness and air gap. Liu and Herrin [9] modified the back cavity of a microperforated plate by partitioning into a number of sub cavities. This was purposely done to improve the sound absorption performance. The result showed that the modifed cardboard cell with honeycomb shaped as the cavity partition improves the absorption performance at approximately 4 dB. Putra and Ismail [10] investigated the sound transmission loss performance of a double-leaf partition with micro-perforated plate insertion. The perforated plate apparently increased the performance of the double-plate particularly at low frequency region. This was a good result since low frequency region is known to be the troublesome frequency in machinery noise. This research was then extended by the same authors with modification on the angle of sound incidence so that the sound transmission performance has been studied in both normal and diffuse field of sound incidence [11]. The effect of hole size on the sound transmission performance has also been explored. It is known that the hole diameter plays as one of the major aspects to increase sound transmission loss performance after perforation ratio [12].

In terms of structural analysis, research on perforated plate has also been of interest. A comprehensive natural frequency and modal analysis study of perforated plates has been done by Burgemeister and Hansen [13]. However, the work was merely limited for macro size holes. The natural frequency and modal analysis was one of the most important aspects to consider in the structural engineering point of view since both relates closely to structural vibration, and structural vibration relates to safety and comfort. This study was then extended by Ismail and Ahmad [14] by taking micro holes into account. The result from both studies shows similar pattern where bigger hole diameter shifts the natural frequency towards lower value. This was a good information whereas many vibration phenomena in machinery happen at low frequency region. For instance, the natural frequency and modal analysis method has been used to examine the perforated plates performance in a nuclear engineering parts [15]. This was a significant proof that perforated plate still performs well in applied engineering.

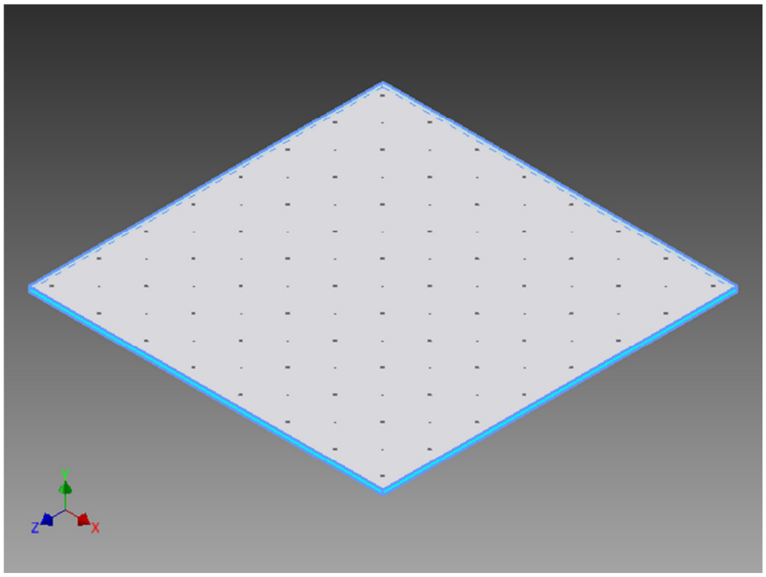
Nevertheless, studies on the combination between macro and micro-size holes on a plate are still apparently lacking. There needs to be an extensive work to investigate the effect of both macro and micro size holes on the plate performance since plate with such perforations have been extensively applied in practice. In this paper, therefore, another extension work of perforated plate has been made where a perforated plate with macro holes (PP) is added with micro holes arranged among the holes. The structural performance is analyzed from the natural frequency and mode shape obtained from the Finite Element (FE) method using Autodesk Inventor Simulation software.

2. Methodology

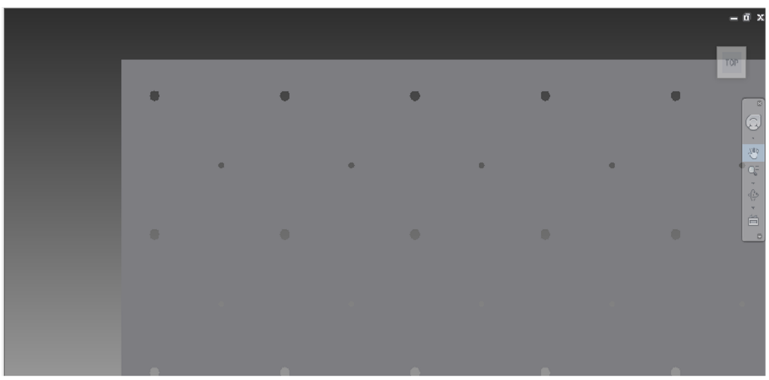
By referring to the previous works [13-15], a model of simply supported 15 x 15 cm square aluminum perforated plate was made in Autodesk Inventor environment as seen in Figure 1(a). The thickness of the plate was set to be constant at 2 mm. While Figure 1(b) depicted how the micro holes were placed among the macro holes to form a diagonal array. The holes on the plate were arranged so that the micro and macro holes distributed evenly on the plate.

In order to particularly understand the effect of micro holes addition, the macro holes diameter were kept constant at 1.5 mm while the micro-holes were varied from 0.25, 0.5, 0.75 to 0.9 mm. In order to simplify the discussion, the name of the samples were made to follow the micro holes diameter i.e. PP25, PP50, PP75 and PP90 respectively. The perforation ratio was kept constant at 0.5% of the plate area, same with the previous works [14].

The total of the model were 4 samples. However, a single perforated plate without micro hole (PP) was also simulated for comparison. This was also to validate the existing model with the previous works. The FE Simulation in Autodesk Inventor were employed to simulate up to the fifth natural frequency and mode shape. The choosing of node density and meshing strategy were following the previous works as well. Table 1 compiles all the models of this project.



(a)



(b)

Fig. 1. (a) Micro holes on a Perforated Plate, (b) Holes Arrangement

Table 1
Samples of the study

Sample Name	Hole Diameter (Macro)	Hole Diameter (Micro)	Perforation Ratio	Nat. Frequency & Mode Shape
PP	1.5 mm	-	0,5 %	1 to 5
PP25	1.5 mm	0,25 mm	0,5 %	1 to 5
PP50	1.5 mm	0,5 mm	0,5 %	1 to 5
PP75	1.5 mm	0,75 mm	0,5 %	1 to 5
PP90	1.5 mm	0,9 mm	0,5 %	1 to 5

3. Results and Discussion

Table 2 Compiles all the simulation results of the models. Generally, all the natural frequencies from 1st to 5th are in the range from 780 to 2860 Hz. It can be seen that the perforated plate without micro holes (PP) has the highest value of all five natural frequencies. As the micro holes are introduced to the plate, the natural frequency moves towards lower frequency. For instance, at the 1st natural frequency, the PP has the frequency of 786,33 Hz while the other plates are in the range around 783 Hz, giving roughly 3 dB of differences. This is similar to previous research [13-15] that the micro holes, somehow, affect the mass of the plate so that the natural frequency value decreases.

Same goes to the 2nd and 3rd natural frequency, the value for PP is at 1601 Hz while the rest of plate with micro holes are at around 1595 to 1596 Hz. Here, 5 to 6 dB's of difference is obtained. The increment of micro hole diameter from 0,25 to 0,75 mm (PP25 to PP75) only gives slight changes of natural frequency. The lowest natural frequency is obtained by plate with 0.9 mm micro holes. This is caused by the fact that 0,9 mm hole diameter is almost close with 1 mm which is the boundary differences between micro and macro perforated hole. The resistive and reactive part inside the holes act similarly one to another. The resistive part comes from the friction between the air and the plate wall inside the hole while the reactive part comes from the inertia of the air mass inside the hole [12]. Since the 0,9 mm hole diameter is close enough with 1 mm perforated plate, the respons from the 0,9 mm hole is then similar with 1 mm hole. In other words, giving 0.9 mm micro holes on the perforated plate is same with doubling the perforated holes in number.

The similar phenomena continues to the 3rd natural frequency. PP90 also gives the lowest natural frequency as the hole affects the plate mass most significantly. At the 4th natural frequency, the difference occurs as the natural frequency gap between PP25 with PP50 is considerable. The gap is now around 2 Hz after the previous gap is only less than 1 dB which can be seen at the 1st , 2nd and 3rd natural frequency. However, the gap becomes small again at the 5th natural frequency.

Table 2
Simulation Results

Model Name	1st Nat. Freq (Hz)	2nd Nat. Freq 2(Hz)	3rd Nat. Freq (Hz)	4th Nat. Freq (Hz)	5th Nat. Freq (Hz)
PP	786,33	1601,06	1601,24	2357,69	2866,91
PP25	783,89	1596,19	1596,50	2352,07	2856,43
PP50	783,85	1596,81	1596,80	2350,63	2856,86
PP75	783,76	1596,13	1596,24	2350,21	2855,32
PP90	783,57	1595,89	1596,96	2349,31	2854,78

Figure 2 shows the mode shape of the plate from the 1st to 5th natural frequencies. At the 1st mode, the maximum deflection is only obtained at the center of the plate. While at the 2nd mode, the maximum deflection happens at 2 locations at each half of the plate which is same with the 3rd mode. The mode divides the plate into 2 section i.e. right and left section and the maximum deflection happens at the center of each section. It can be said that that there are two peaks at one plate. Meanwhile, the 4th mode has similar pattern with the 5th mode. The mode now divides the plate into 4 sections diagonally. Maximum deflection happens at the center of each section. But, the location of the deflection is different each other. For the 4th mode, the maximum deflections are placed at the four corners of the plate, while for the 5th plate the maximum deflection locations are at the four sides of the plate. These are quite interesting and need to be invstigated particularly in the future. Nevertheless, all the mode shapes obtained in this work are similar with the previous works using Solid Work Simulation [14].

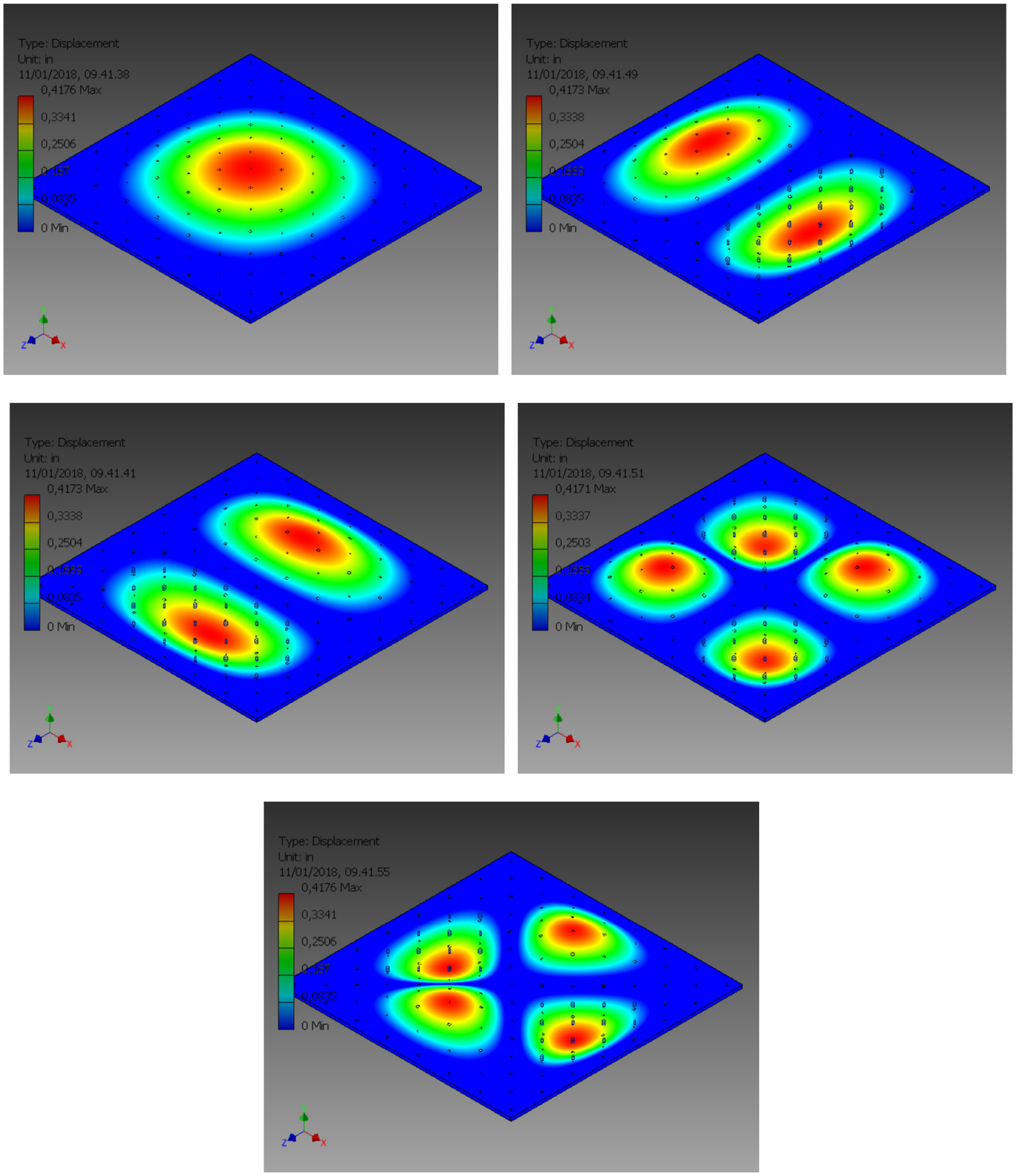


Fig. 2. 1st to 5th Mode Shape

4. Conclusion

The natural frequency of perforated panels with micro holes addition on the plate has been studied. Similar pattern with the previous works has been detected. The addition of micro holes affects the mass of plate and eventually reduces the natural frequency to the lower value. It is also proportional to the micro holes diameter. However, future investigation on the effect of micro and macro holes arrangement is needed in order to enhance the fundamental findings.

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