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DYNAMIC RESPONSE ANALYSIS OF RECTANGULAR PERFORATED PLATES WITH VARYING SIZES OF CIRCULAR PERFORATION HOLES

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Abstract

In this work vibration characteristics of rectangular perforated plates with varying sizes of circular perforation holes arranged in diagonal array are investigated. Natural frequencies of free vibration of the perforated plates and the corresponding mode shapes are obtained experimentally and also numerically. Numerical analysis of dynamic characteristics of perforated plates is carried out using ANSYS, the FEM analysis software package and the experimental analysis is carried out using FFT analyzer, accelerometer and impact hammer. Parameters defining the geometry of holes in a perforation array are presented, as well as the ratio of modal resonance frequencies of a perforate to those of a corresponding solid panel, termed the effective resonance frequency is introduced. In addition, the curve fitting technique is utilized to find the relationship of the mass remnant ratio with the effective resonance frequency. The functions obtained from curve fitting can be used to predict accurately the effective resonance frequencies of wide range of perforation geometries.

Key words: Vibration characteristics, perforated plates, Effective resonance frequency, Mass remnant ratio, Curve fitting

1. INTRODUCTION

There is an impressive variety of possibilities for the use of perforated products, which are found in nearly all branches of industry. Since perforated products reduce the weight and improve certain properties, they are getting more applications in engineering designs. Dynamic response analysis of perforated plates is a field of diverging scope and plenty of research work is being done on different kinds of plates. The objective of this work was to investigate generalized equations for free vibrations of rectangular perforated plates. All the panel geometry parameters of rectangular perforated plates are considered carefully while obtaining the required relations between *the mass remnant ratio and effective resonance frequency.*

2. PANEL GEOMETRY PARAMETERS

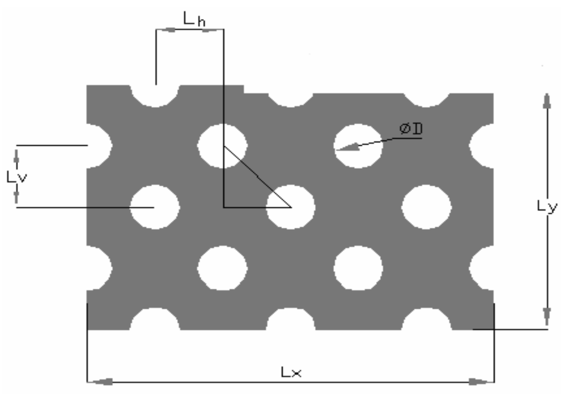

Figure 1. Panel geometry parameters

The pitch between holes in a perforated material and the diameter of holes are important panel geometry parameters. The Fig 1 shows perforation holes in rectangular perforation array. L_h is the horizontal spacing between two successive columns and L_v is vertical spacing between two successive rows. L_x is the total length of perforated plate and L_y is the total breadth of plate. The specimens investigated in this work include a full flat plate and five perforated plates arranged in diagonal array. As 45^0 degree staggered center round hole pattern is most strong and most popular, this pattern is selected for investigation.

3. MASS REMNANT RATIO

Mass Remnant ratio of a perforated plate is defined as the ratio of surface area of perforated plate to that of a full flat plate of the same dimensions. Mass remnant ratio of the perforated plate with holes of radius r as shown in Fig1 is given by,

$$MR = 1 - \frac{\pi r^2}{2L_v L_h} \qquad \text{……….} (1)$$

4. TEST SPECIMENS

Experimentation is carried out on six different rectangular specimens. All the six specimens tested are of length L_x = 216mm, breadth L_y = 162mm and thickness of 2.3mm. Specimen 1 is a full flat pate and Specimen 2 is a perforated plate having holes of diameter 4mm, with L_h = 27mm and Lv = 27mm. Specimen 3, specimen 4, specimen 5 and specimen 6 are perforated plates with holes of diameters 6mm, 8mm, 10mm and 12mm respectively; the other dimensions of these specimens i.e. horizontal spacing between holes, vertical spacing between holes, overall length of plate and overall breadth of plate being exactly the same as specimen 2. All the six specimens are made of M.S, having material properties of, Young's modulus E=2.1X10 ^{11} N/m^2, Poisson's ratio = 0 .3 & density of material = 7850 kg/m^3.

5. EXPERIMENTAL & NUMERICAL ANALYSIS

The experimental analysis of natural frequencies of perforated plates is carried out using FFT analyzer, accelerometer and impact hammer. Precise fixture plates are fabricated to apply the required boundary conditions of all four outside edges fixed. Numerical analysis of dynamic characteristics of perforated plates is carried out using ANSYS the FEM analysis software package. The Shell element, Shell 63 in ANSYS is selected with four nodes on each element.

6. RESULTS AND DISCUSSION

6.1 Discussion on FEM results

The natural frequencies of vibration of the full flat plate and five perforated plates obtained by FEM analysis software ANSYS are tabulated in Table 1.

Table 1. Natural Frequencies of test specimens (Hz) obtained experimentally & by Numerical analysis

Specimens	Diameter of Holes (mm)	Numerical Results(FEM)			Experimental Results		
		Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
Specimen 1	---	626.22	1050.4	1473.2	684.3	1021.8	1368.7
Specimen 2	4	625.16	1047.2	1469.9	628.1	1053.1	1362.5
Specimen 3	6	620	1040.3	1457.5	634	990	1359
Specimen 4	8	616.33	1033.1	1447.9	643.75	1050	1290
Specimen 5	10	611.43	1024.9	1436.1	687	1100	1381
Specimen 6	12	605.97	1016.5	1424.6	640	1075	1334

For each of the six specimens natural frequencies of three modes of vibration are obtained and the corresponding mode shapes are also obtained. From the results obtained, it can be seen that the natural frequency of vibration for all the modes decreases as the diameter of perforation holes increase (Fig 2). Irrespective of the sizes of perforation holes and even for the full flat plate the mode shapes of vibration are the same.

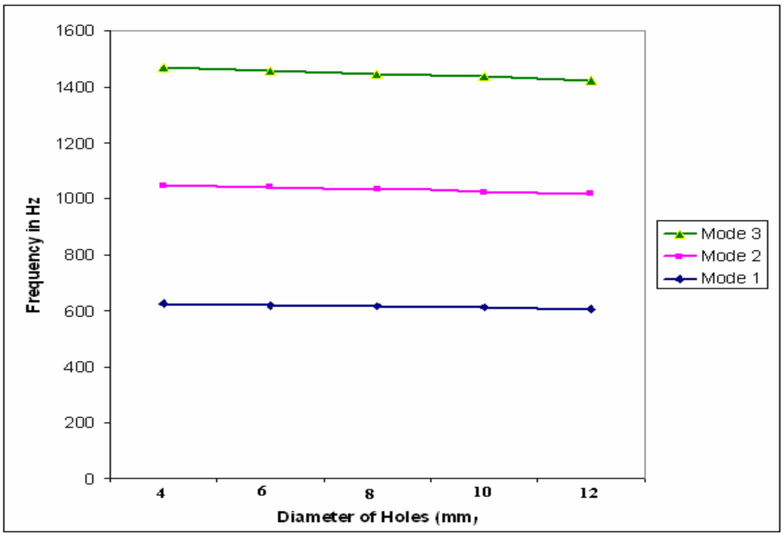

Figure 2. Plot of natural frequencies Vs diameter of perforation holes for mode1, mode2 & mode3

6.2 Discussion on Experimental results

The experimental results obtained by FFT analyzer for all the specimens are tabulated in Table 1. The Frequency spectrums are also obtained in experimental analysis. First, second and third natural frequencies are obtained for the full flat plate and five perforated plates.

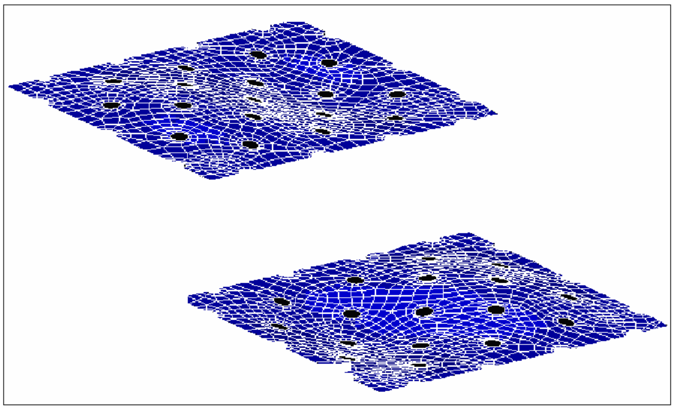

Figure 3. Second mode (mode 2) of vibration of specimen 5.

7. CURVE FITTING FOR EFFECTIVE RESONANCE FREQUENCY OF PERFORATED PLATES:

In this article, the curve fitting technique is utilized to find the relationship of mass remnant ratio (MR) with the *effective resonance frequency*. Fifteen data points are adopted (three data points from each of the perforated plate) from the frequency ratios to determine the curve fitting functions.

It should be pointed out that, when the radius of the holes approaches zero, i.e. holes of the perforated plate become very small or the perforated plate becomes a full flat plate, no appropriate curve fitting function can be found between the "Frequency Ratio" and the MR (Mass Remnant Ratio). In fact, the distribution of the frequency ratio is not quite linear. In particular, when the MR approaches 1, the slope of the fitting curve becomes rather small. It is therefore necessary to increase the power of MR to magnify the difference of the frequency ratio. Finally the cube of the MR i.e. $(MR)^3$, was found appropriately to process the curve fitting and the obtained function is shown in Fig 4 and Fig 5. This function can be used to predict the trend of natural frequencies of free vibration of the perforated plates in diagonal array. The function is expressed as, $Y = aX^4 + bX^3 + cX^2 + dX + e$. Where X is Cube of Mass Remnant Ratio $(MR)^3$, Y is *Effective resonance frequency*$(f\ /\ f^{*})$, and a,b,c,d,e are the coefficients of this function, listed in Table 2.

Table 2. Coefficients of Curve fitting function

Mode No	a	B	C	D	e
Mode 1	-16.493251	58.671369	-77.459040	45.138928	-8.852868
Mode 2	-4.592874	16.490461	-21.811942	12.749913	-1.832918
Mode 3	-14.430626	51.108889	-67.052231	38.772797	-7.394015

To verify the validity of fitting function two new perforated specimens (L_h = 27mm, L_v = 27mm , Dia=5mm and L_h = 50mm, L_v =50mm , Dia= 10mm) are used. The results obtained from the fitting function are listed in Table 3 for new specimen 1 and in

Table 4 for new specimen 2. The difference between the predicted and ANSYS results is less than 0.5 %.

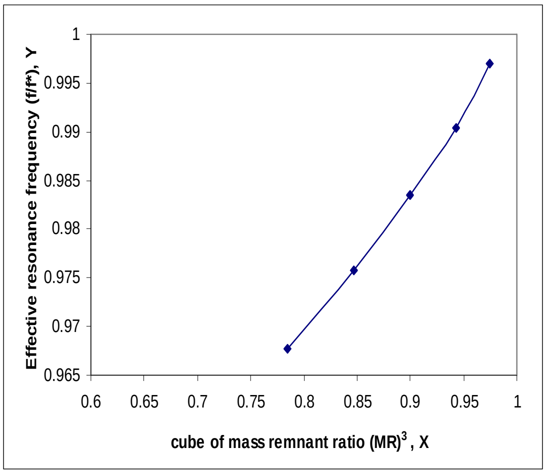

Figure 4. Curve of Effective resonance frequency Vs $(MR)^3$, for vibration mode 2

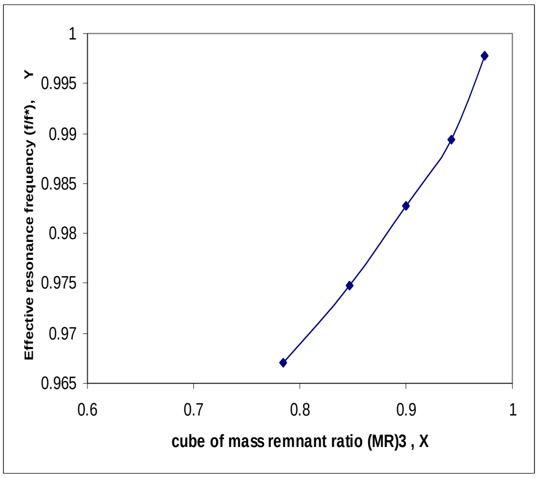

Figure 5. Curve of Effective resonance frequency Vs $(MR)^3$, for vibration mode 3

Table 3: Predicted natural frequencies of perforated new specimen 1 (Hz)

New Specimen 1 (Lx=216mm,Ly=162mm,thickness=2.3mm,L_h = 27mm, L_v = 27mm , Dia= 5mm).			
	Mode 1	Mode 2	Mode 3
Prediction from Curve	622.76	1043.99	1464.13
ANSYS	623.58	1044.6	1466
%Difference	0.1	0.05	0.1275

Table 4. Predicted natural frequencies of perforated new specimen 2 (Hz)

New Specimen 2 (Lx=300mm,Ly=200mm,thickness=2.5mm,L_h = 50mm, L_v = 50mm , Dia= 10mm)			
	Mode 1	Mode 2	Mode 3
Prediction from Curve	414.4	641.22	1013.46
ANSYS	416.58	644.42	1014.7
%Difference	0.5	0.48	0.09

8. CONCLUSION

In this work very important facts about the vibrations of perforated plates are investigated like, for all the perforated plates having the same mass remnant ratio (larger plates or smaller plates) effective resonance frequency ratio remains constant; as the mass remnant ratio of a perforated plate reduces i.e. as the surface area of plate reduces by having perforation holes i.e. as the opaqueness of perforated plate reduces its natural frequency of free vibration also reduces for all modes; as the thickness of perforated plate varies keeping the diameter of holes and spacing between the holes constant the effective resonance frequency ratio remains constant. Further using curve fitting technique the fourth order equation $Y = aX^4 + bX^3 + cX^2 + dX + e$, is fit precisely between *Effective resonance frequency and Mass remnant ratio.* This function can be used to determine the effective resonance frequency ratio for a large range of panel geometries with an error of less than ±0.5%. The validity of these curve fitting functions obtained is verified by using two new specimens and it is seen that the results obtained are much close to actual results. Also using these functions natural frequencies can be obtained immediately.

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