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Modal Analysis of Perforated Plates

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***Abstract*: A mode shape is a specific pattern of vibration executed by a mechanical system at a specific frequency. Different mode shapes will be associated with different frequencies. The experimental technique of modal analysis discovers these mode shapes and the frequencies. In this paper modal analysis has been carried out to determine the mode shapes and the respective frequencies of perforated plates with regard to change in the dimension of the perforations and the distance between the perforations (pitch).**

***Keywords*: mode shape, convergence study, perforated plate, frequency.**

1. Introduction

Perforated metal, also known as perforated sheet, perforated plate, or perforated screen, is sheet metal that has been manually or mechanically stamped or punched to create a pattern of holes, slots, or decorative shapes. Materials used to manufacture perforated metal sheets include stainless steel, cold rolled steel, galvanized steel, brass, aluminium, copper, Monel, Inconel, titanium, plastic, and more.

The process of perforating metal sheets has been practiced for over 150 years. In the late 19th century, metal screens were used as an efficient means of separating coal. The first perforators were labourers who would manually punch individual holes into the metal sheet. This proved to be an inefficient and inconsistent method which led to the development of new techniques, such as perforating the metal with a series of needles arranged in a way that would create the desired hole pattern.

Modern day perforation methods involve the use of technology and machines. Common equipment used for the perforation of metal include rotary pinned perforation rollers, die and punch presses, and laser perforations.

2. Applications of perforated plates:

Architectural - infill panels, sunshade, cladding, column covers, metal signage, site amenities, fencing screens, etc.

Food & beverage - beehive construction, grain dryers, wine vats, fish farming, silo ventilation, sorting machines, fruit and vegetable juice presses, cheese molds, baking trays, coffee screens, etc.

Chemical & energy - filters, centrifuges, drying machine baskets, battery separator plates, water screens, gas purifiers, liquid gas burning tubes, mine cages, coal washing, etc.

Material development - glass reinforcement, cement slurry screens, dyeing machines, textile printers and felt mills, cinder screens, blast furnace screens, etc.

Automotive - air filters, oil filters, silencer tubes, radiator grilles, running boards, flooring, motorcycle silencers, ventilation grids, tractor engine ventilation, sand ladders and mats, etc.

Construction - ceiling noise protection, acoustic panels, stair treads, pipe guards, ventilation grilles, sun protection slats, facades, sign boards, temporary airfield surface, etc.

3. Benefits

The acoustic performance of perforated metal helps people or workers to limit health effects from noise. Studies have shown that perforated metals help reduce sound levels. Studies have shown that having buildings use perforated metal sheets in front of their façade can bring in one study 29% energy savings (HVAC + Lighting estimated consumption in 1 year) and in the second one 45% energy savings (heating, ventilation, air conditioning). Depending on the location of the building (intensity of the external sun), solar irradiation can be decrease by 77.9%.

Modal analysis of oscillating systems determines eigen modes and eigen values. These values can be determined by the simulation (eigen values) or experiment (natural frequencies and mode shapes). The eigen modes and the eigen values are used to investigate the vibration of mechanical structures, to diagnose architectural and engineering constructions. It is one of the basic dynamics methods. The principle of modal analysis is based on the possibility of decomposition of oscillatory motion for partial (also modal, own) parts. The resulting motion is created by superposing of these parts. Each part of the oscillating movement is characterized by its own frequency, Eigen modes and the corresponding damping mode shape. A complete description of the dynamic mechanical system is obtained by determining the modal properties of the resulting parts [2].

The aim of the modal analysis is to find the natural frequencies and mode shapes of the system (parts). Modal, harmonic analysis is one of the dynamic analysis, at solutions we are considering the inertia of the system.

In case of perforated plates, the perforations are done in the form of rectangular arrays on a rectangular plate as shown in

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Table 1
Comparison of frequency for variation in diameter of hole

Mode Shape	Solid Plate f(Hz)	Diameter of Hole =5mm f(Hz)	Diameter of Hole =10mm f(Hz)	Diameter of Hole =15mm f(Hz)	Diameter of Hole =20mm f(Hz)	Diameter of Hole = 25mm f(Hz)
1	74.3844	74.246	73.0291	71.7674	70.0228	68.0082
2	161.594	161.306	158.572	155.918	152.226	147.848
3	210.904	210.328	206.834	203.591	198.508	192.806
4	297.839	297.608	292.199	288.003	281.114	273.75
5	307.514	306.632	301.341	296.614	289.848	281.684
6	439.695	437.562	430.039	424.511	414.27	402.666
7	442.377	443.379	434.793	429.336	419.319	408.749
8	512.874	510.477	501.357	494.707	484.138	470.274
9	526.297	525.39	515.335	509.504	497.543	485.022
10	684.286	647.95	634.688	628.442	614.327	485.022

the figure below.

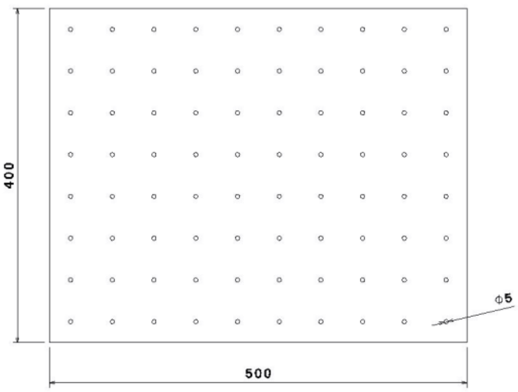


Fig. 1. Perforated aluminium plate

The plate thickness is 3mm and the material properties are: E=70GPa, ρ=2700Kg/m^3 and ϑ=0.3

The frequencies for the first 10 modes are obtained by solving this problem in ANSYS software by taking 3D 4node 181 shell element.

The analysis was made by increasing the size of the hole and by increasing the distance between the holes. The results are tabulated below.

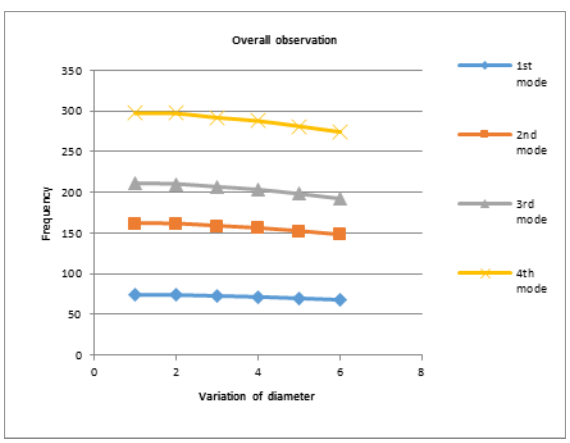
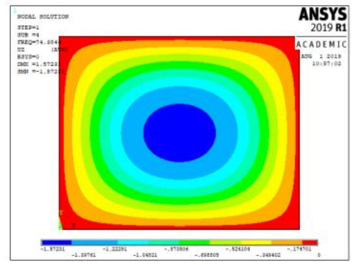
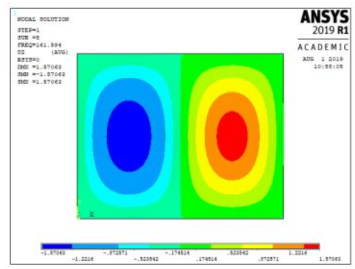


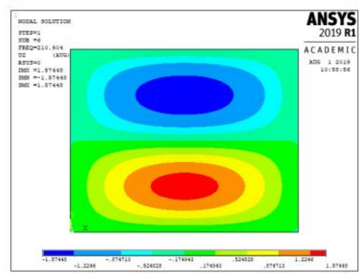
Fig. 2. Chart for overall observation of perforated aluminium plate for variation in diameter of the hole

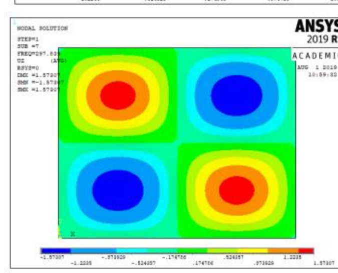
The various mode shapes obtained for all the perforated plates are shown below.

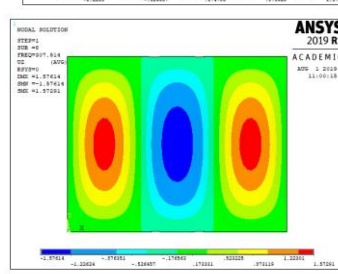


1) Solid plate









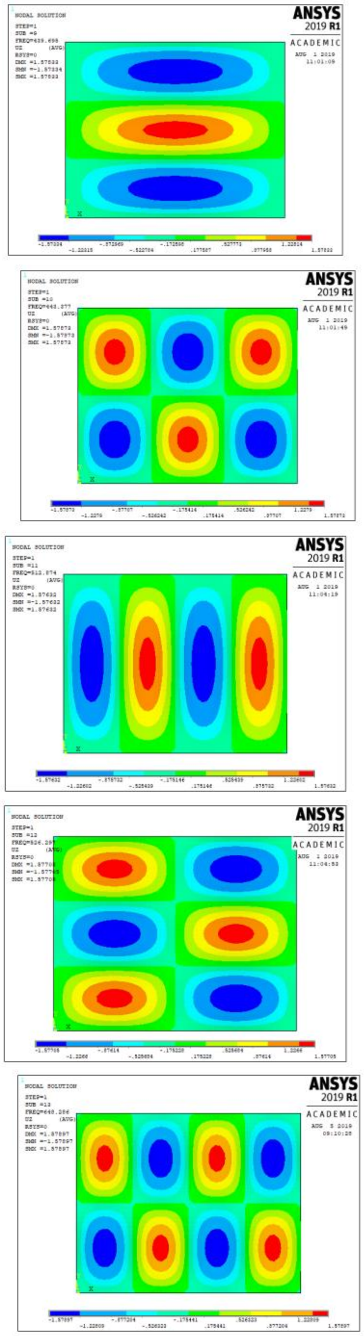
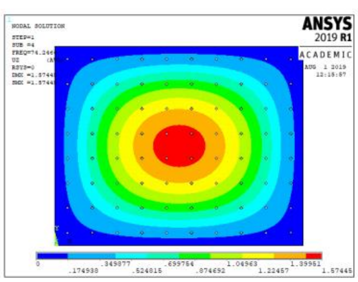
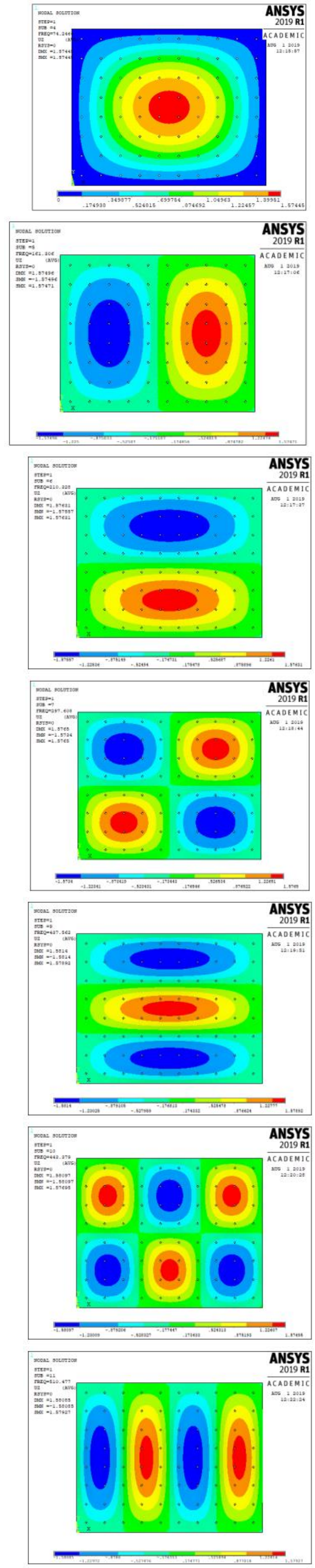


Fig. 3. Set of mode shapes for the first 10 modes of the solid aluminium plate

2) Perforated plate with hole diameter=5mm





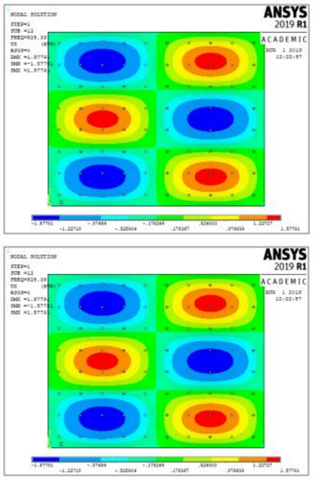
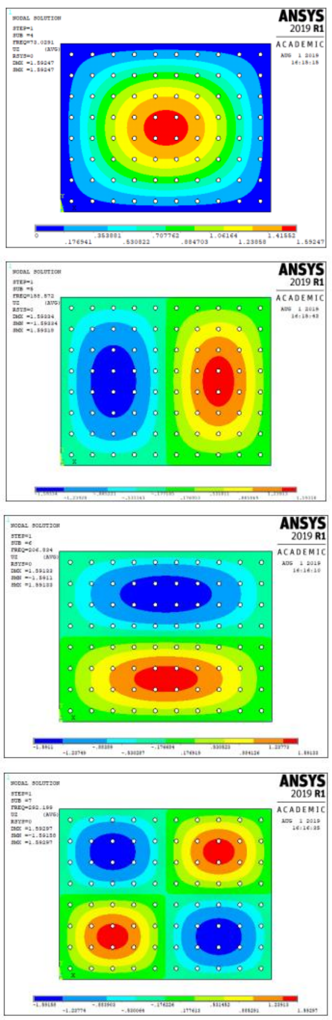


Fig. 4. Set of mode shapes for the first 10 modes of the perforated plate with diameter of the hole=5mm

3) *Perforated plate with hole diameter=10mm*



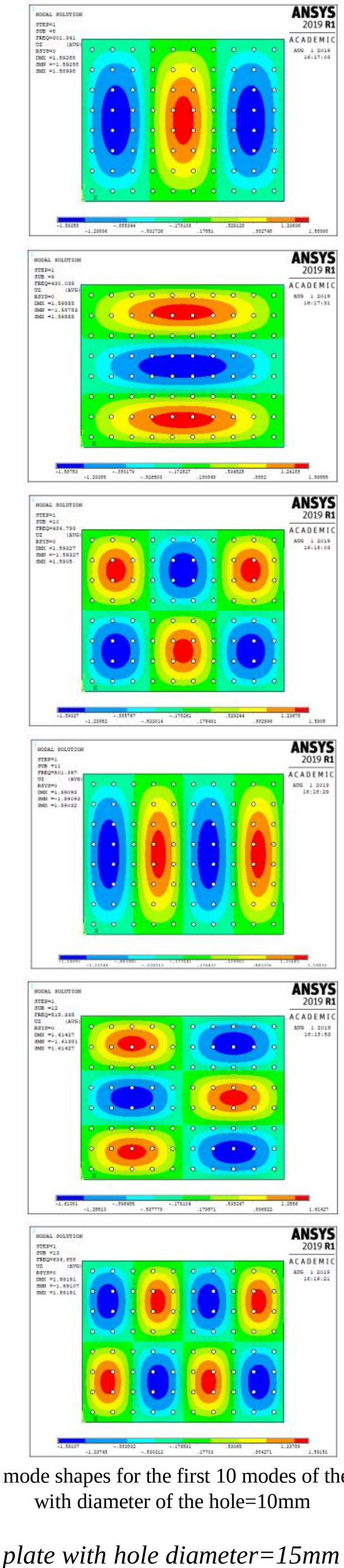
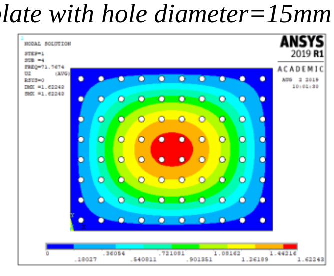
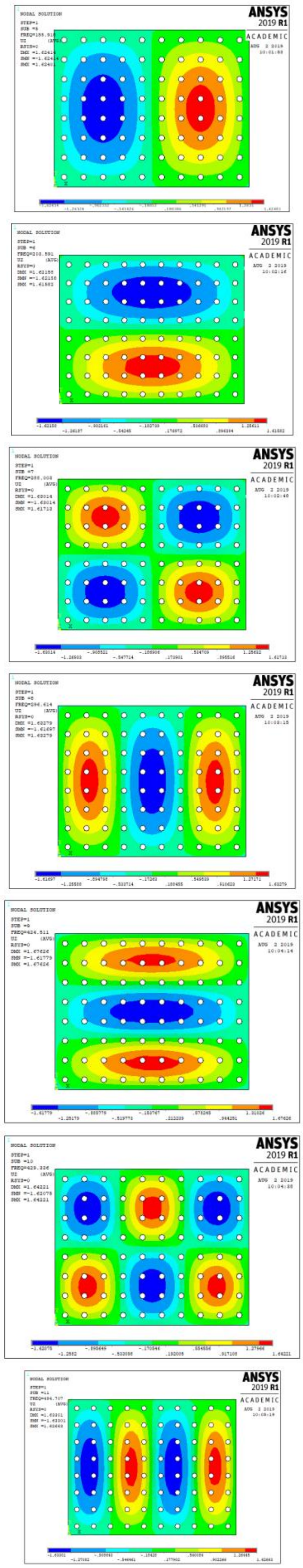


Fig. 5. Set of mode shapes for the first 10 modes of the perforated plate with diameter of the hole=10mm

4) *Perforated plate with hole diameter=15mm*





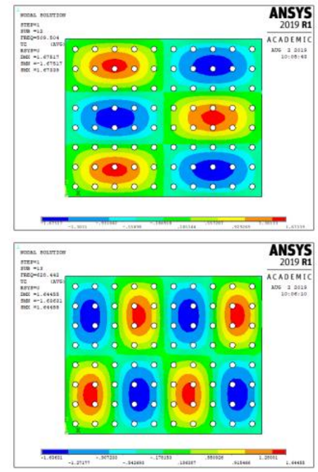
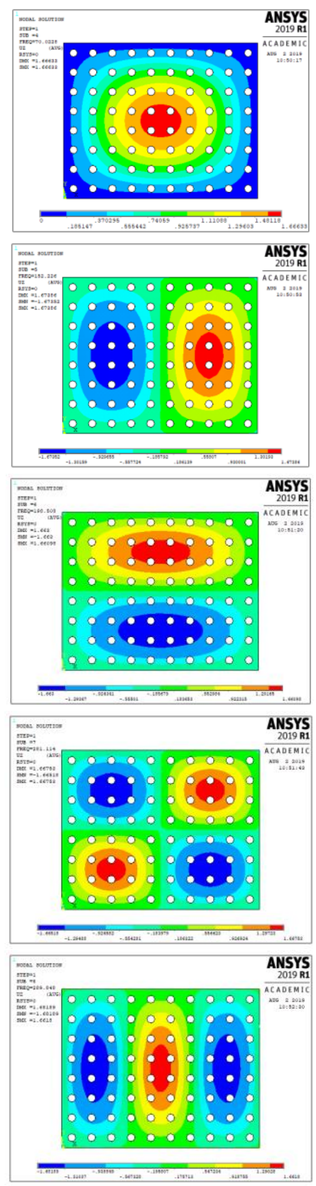


Fig. 6. Set of mode shapes for the first 10 modes of the perforated plate with diameter of the hole=15mm

5) Perforated plate with hole diameter=20mm



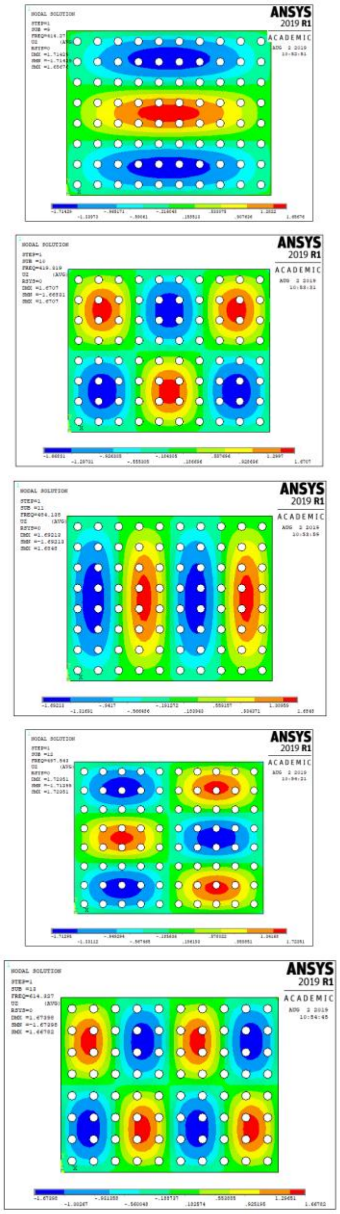
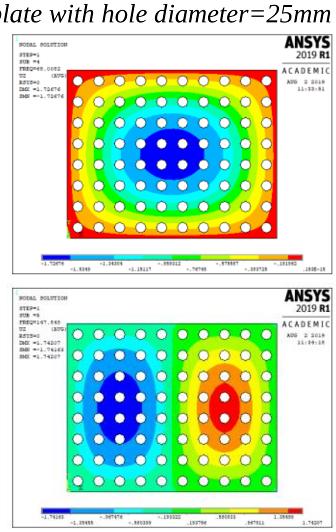
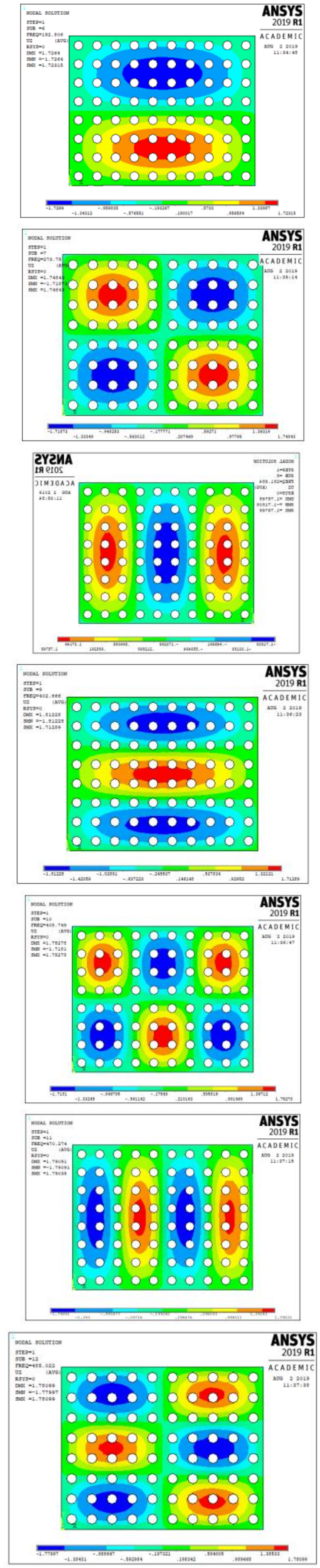


Fig. 7. Set of mode shapes for the first 10 modes of the perforated plate with diameter of the hole=20mm

6) *Perforated plate with hole diameter=25mm*





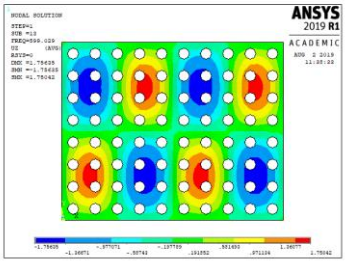


Fig. 8. Set of mode shapes for the first 10 modes of the perforated plate with diameter of the hole=25mm

From this analysis it is found that the frequencies decreases as the size of the hole increases. Also it is observed that the frequency reduces for every increase in the diameter according to the mode shape.

For a particular mode, the frequency reduces by very small quantity as the size of the hole increases as observed from the graphs obtained.

A convergence study has been carried out to understand the behaviour of the perforated plates with the increase in the number of elements of the continuum. The results are tabulated and necessary graphs are shown below.

It was observed that due to the perforations the mode shapes obtained were irregular when the continuum was divided into very few elements as shown in the figure below.

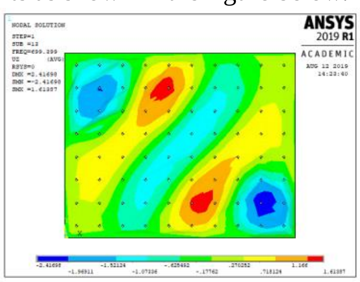


Fig. 9. Irregular mode shape of the perforated plate

When the diameter of hole=5mm, the convergence is as shown below.

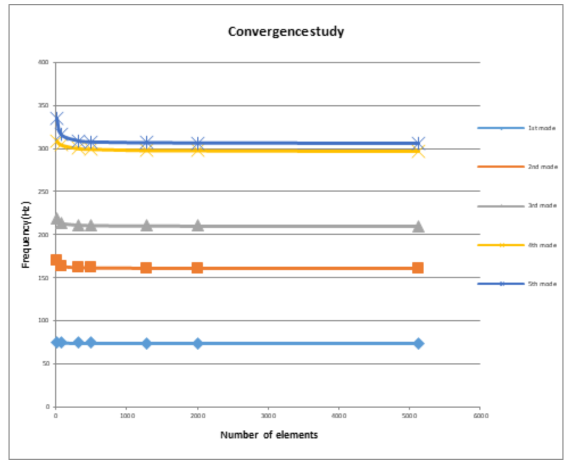


Fig. 10. Chart of convergence study of perforated aluminium plate when diameter of hole=5mm

When the diameter of hole=10mm, the convergence is as shown in table 3.

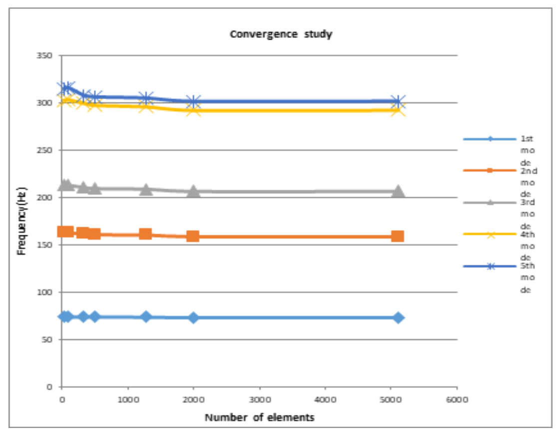


Fig. 11. Chart of convergence study of perforated aluminium plate when diameter of hole=10mm

Table 2
Frequencies of the first 10 modes of perforated aluminium plate when diameter of hole=5mm

S.No.	f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
1	75.602	74.798	74.454	74.404	74.271	74.246	74.165
2	170.083	163.809	162.02	161.787	161.371	161.306	161.062
3	219.31	213.735	211.434	211.005	210.409	210.328	210.013
4	309.273	304.47	300.095	299.373	297.794	297.608	296.846
5	335.091	316.233	309.078	307.786	306.777	306.632	306.013
6	459.459	449.518	441.177	439.857	437.796	437.562	436.576
7	479.681	460.445	449.033	446.976	443.739	443.379	441.798
8	564.424	530.826	515.881	513.034	510.658	510.477	509.048
9	621.087	549.212	531.744	529.727	525.696	525.39	523.491
10	699.399	670.871	657.76	654.891	648.544	647.95	644.974

Table 3
Frequencies of the first 10 modes of perforated aluminium plate when diameter of hole=10mm

S.No.	f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
1	74.768	74.504	74.101	73.918	73.756	73.0291	73.035
2	163.585	163.289	161.506	160.771	160.289	158.572	158.603
3	212.998	212.869	210.661	209.639	209.025	206.834	206.866
4	302.861	303.489	299.726	297.471	295.931	292.199	292.321
5	314.983	316.007	307.721	306.058	304.785	301.341	301.425
6	446.488	447.75	439.951	437.748	435.141	430.039	430.251
7	460.387	458.523	449.273	444.121	441.158	434.793	435.096
8	531.229	527.132	514.144	510.152	507.529	501.357	501.52
9	550.161	545.081	531.938	526.962	522.8	515.335	515.695
10	669.061	669.086	659.795	650.632	644.903	634.688	535.23

When the diameter of hole=15mm, the convergence is as shown in table 4.

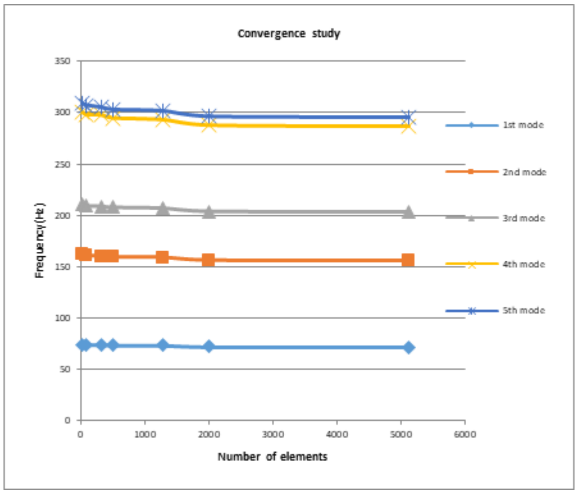


Fig. 12. Chart of convergence study of perforated aluminium plate when diameter of hole=15mm

When the diameter of hole=20mm, the convergence is as shown table 5.

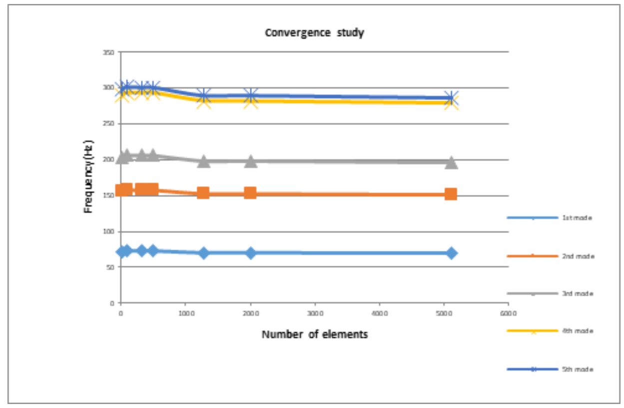


Fig. 13. Chart of convergence study of perforated aluminium plate when diameter of hole=20mm

When the diameter of hole=25mm, the convergence is as shown table 6.

Table 4
Frequencies of the first 10 modes of perforated aluminium plate when diameter of hole=15mm

S.No.	f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
1	73.717	73.484	73.519	73.151	72.977	71.7674	71.633
2	161.494	160.284	160.171	159.054	158.642	155.918	155.587
3	210.779	209.375	208.656	207.681	206.837	203.591	202.926
4	300.021	298.079	297.469	294.756	293.143	288.003	286.927
5	308.651	307.185	305.053	303.011	301.688	296.614	295.711
6	442.977	441.325	435.013	432.865	430.591	424.511	422.231
7	453.852	448.689	446.024	440.206	437.382	429.336	427.198
8	525.246	516.027	508.832	504.874	502.431	494.707	492.369
9	536.28	533.436	527.43	521.853	518.131	509.504	506.378
10	671.356	662.616	655.048	644.747	639.92	628.442	624.132

Table 5
Frequencies of the first 10 modes of perforated aluminium plate when diameter of hole=20mm

S.No.	f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
1	71.912	72.414	72.475	72.477	70.043	70.0228	69.464
2	156.947	157.873	157.78	157.825	152.326	152.226	150.894
3	203.355	205.682	205.641	205.735	198.496	198.508	196.742
4	289.846	292.806	292.819	292.945	281.718	281.114	278.431
5	298.395	301.066	300.504	300.523	289.877	289.848	286.83
6	422.911	430.221	429.106	429.229	413.91	414.27	409.531
7	433.133	440.567	438.529	438.734	420.58	419.319	414.757
8	497.195	504.458	501.228	501.574	483.847	484.138	477.743
9	512.192	521.082	519.684	519.566	498.654	497.543	491.586
10	638.908	648.75	643.602	645.445	616.334	614.327	606.118

Table 6
Frequencies of the first 10 modes of perforated aluminium plate when diameter of hole=25mm

S.No.	f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
1	72.256	73.031	71.154	71.29	68.034	68.0082	67.218
2	157.731	159.8	154.949	155.202	148.059	147.848	145.962
3	206.247	207.331	201.837	202.314	193.002	192.806	190.088
4	296.245	298.136	287.541	288.226	274.031	273.75	269.576
5	305.452	304.642	295.251	295.437	281.985	281.684	277.275
6	436.937	430.509	421.577	422.266	403.579	402.666	395.449
7	454.771	451.661	431.314	432.07	409.119	408.749	401.8
8	508.528	512.286	493.312	492.728	471.346	470.274	461.653
9	533.562	532.279	510.546	511.589	485.958	485.022	475.637
10	666.864	665.509	634.557	634.826	600.199	485.022	587.074

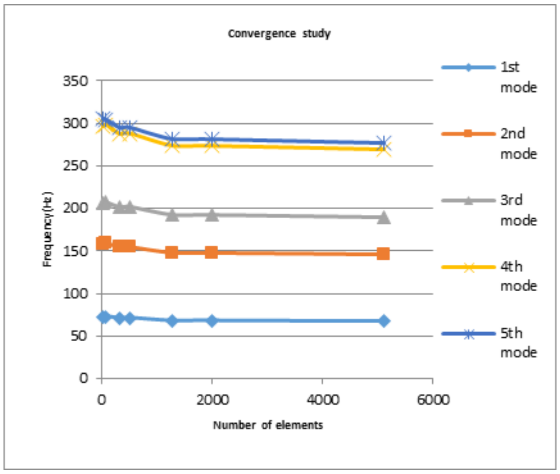


Fig. 14. Chart of convergence study of perforated aluminium plate when diameter of hole=25mm

Hence from the convergence study of the perforated plates with increasing size of the perforations we can conclude that the frequency of the perforated plate converges and tends to become a constant as the number of elements of the continuum increases and becomes consistent. This consistent value of frequency is used to analyse the behaviour of the perforated plate and is compared with the experimental and analytical frequency.

Further another analysis was made to observe the trend or behaviour of the perforated plate wherein the pitch of the holes were varied. The resuts of this analysis is tablated below.

Table 7
Comparison of frequency for variation of pitch of the perforations

Mode Shape	Zig-Zag (25-25)	Zig-Zag (50-50)	Zig-Zag (75-75)	Zig-Zag (100-100)
1	74.0533	74.2512	74.3639	74.3774
2	160.865	161.322	161.56	161.585
3	209.731	210.362	210.704	210.77
4	296.363	297.702	298.03	298.09
5	305.858	306.656	307.189	307.207
6	436.581	437.627	438.527	438.658
7	441.813	443.57	443.972	443.979
8	509.347	510.423	511.366	511.627
9	523.83	525.567	526.284	526.368
10	645.357	648.163	648.645	649.038

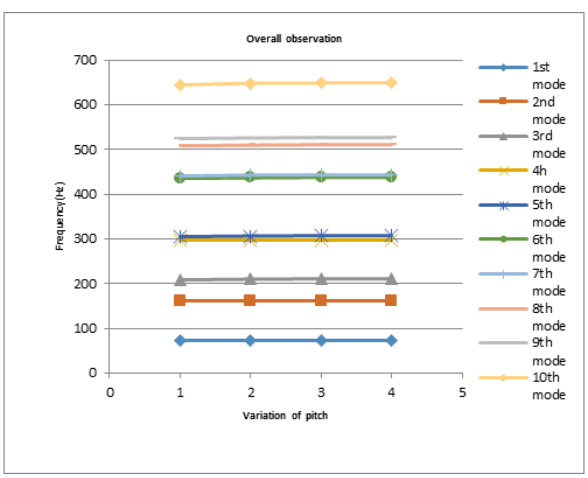
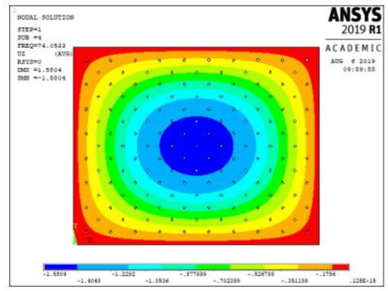


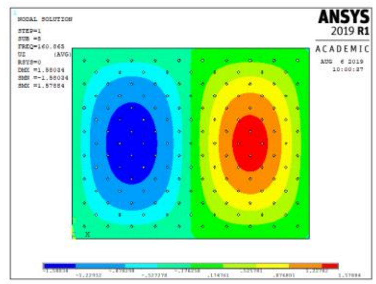
Fig. 15. Chart showing the overall observation of the modal analysis of perforated aluminium plate

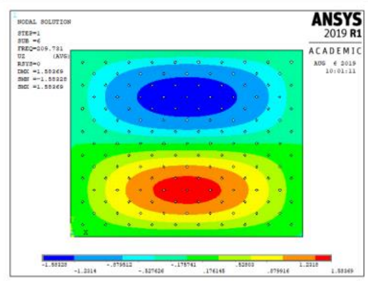
From the above analysis it is observed that the frequency is consistent for variation of pitch as the diameter of the hole is constant at 5mm and when all the data are combined we can observe that there is very negligible deviation of one point from another. There might be a deviation in the range of frequencies if the size of the hole is increased, but as per the above concerned case here is no much deviation and the range of frequencies is found to be consistent.

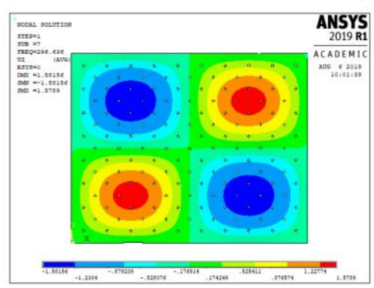
The mode shapes of the perforated plate with variation in pitch is as shown in the figures below.

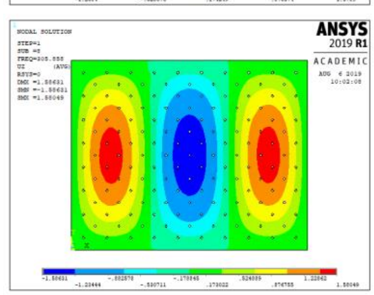
7) Pitch=25mm











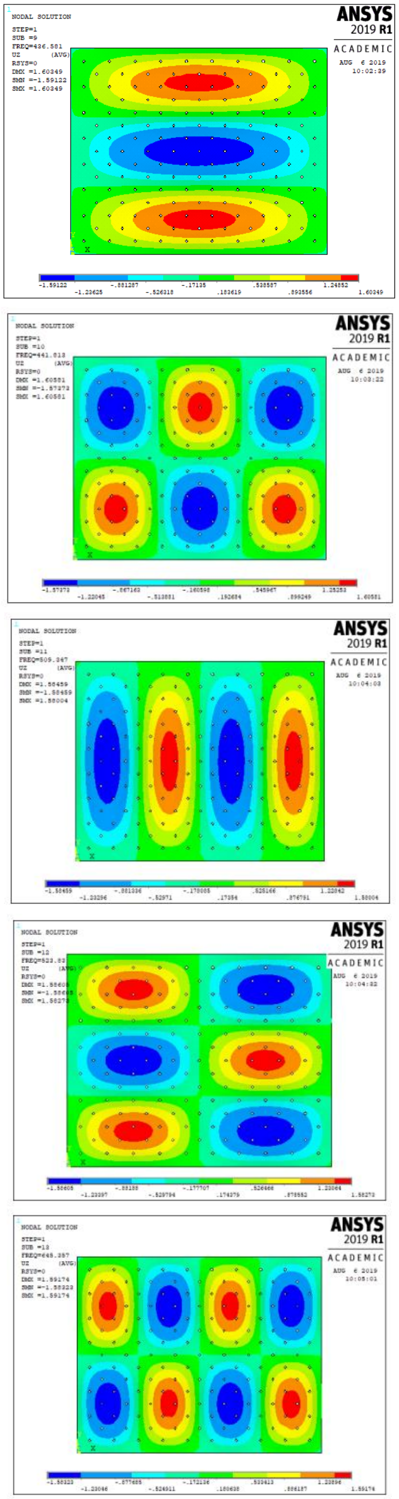
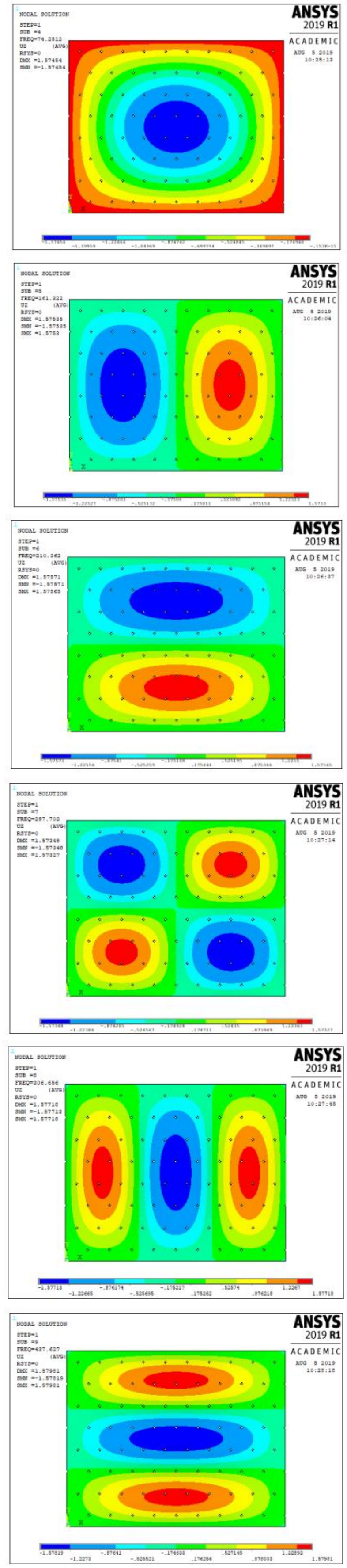


Fig. 16. Set of mode shapes for the first 10 modes of perforated aluminium plate with pitch=25mm

8) Pitch=50mm



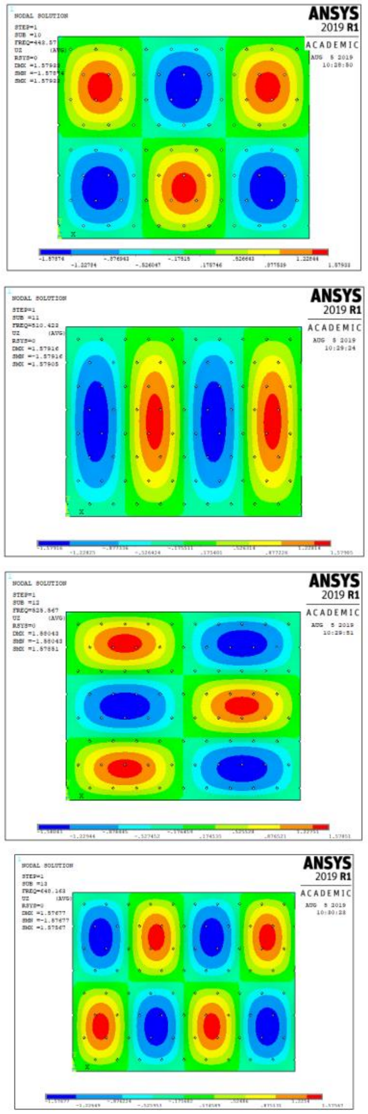
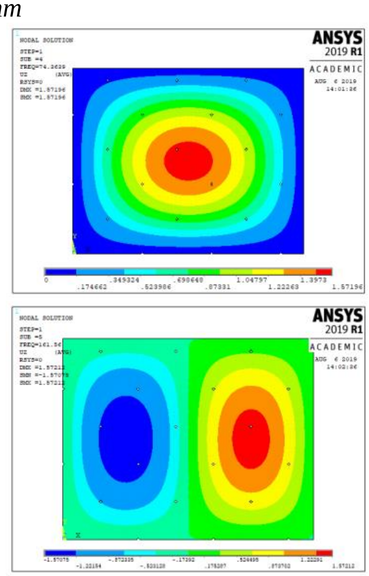
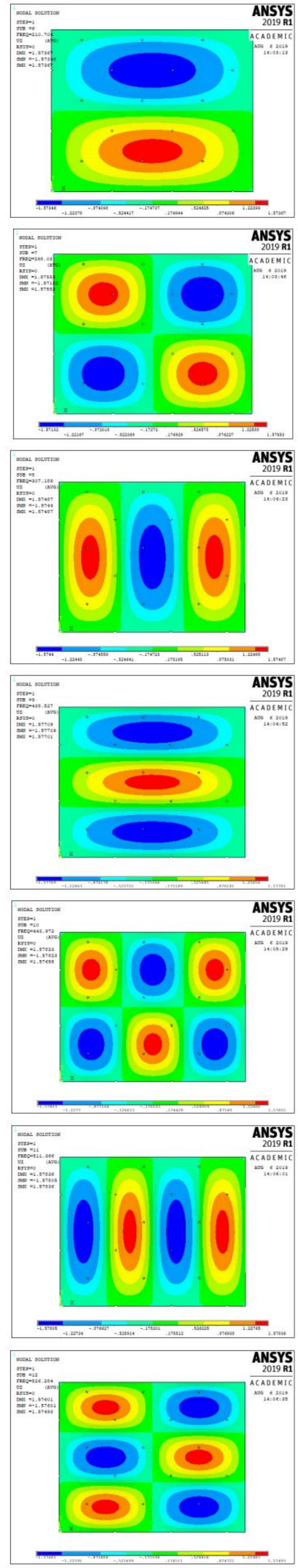


Fig. 17. Set of mode shapes for the first 10 modes of perforated aluminium plate with pitch=50mm

9) *Pitch=75mm*





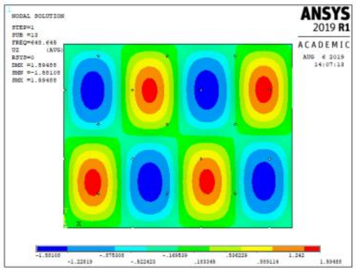
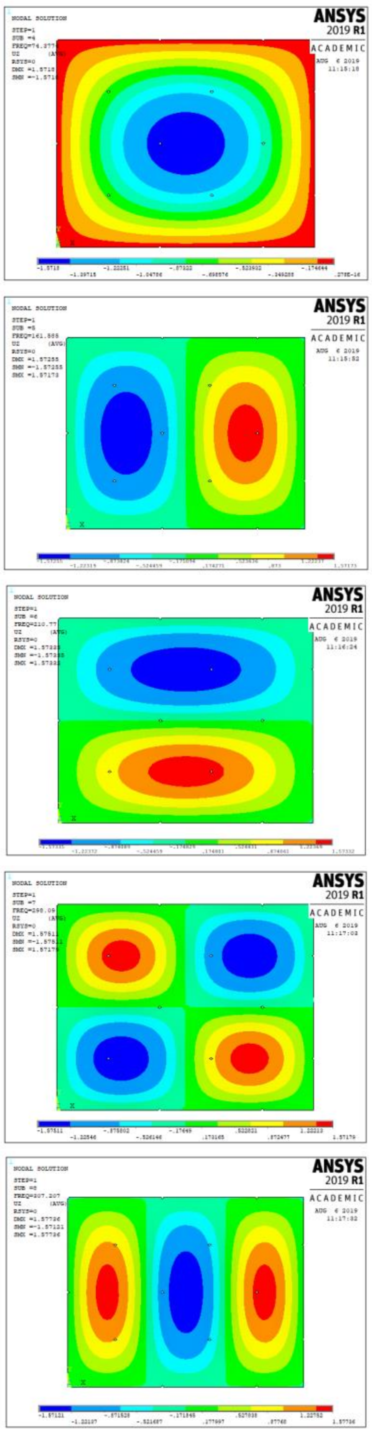


Fig. 18. Set of mode shapes for the first 10 modes of perforated aluminium plate with pitch=75mm

10) Pitch=100mm



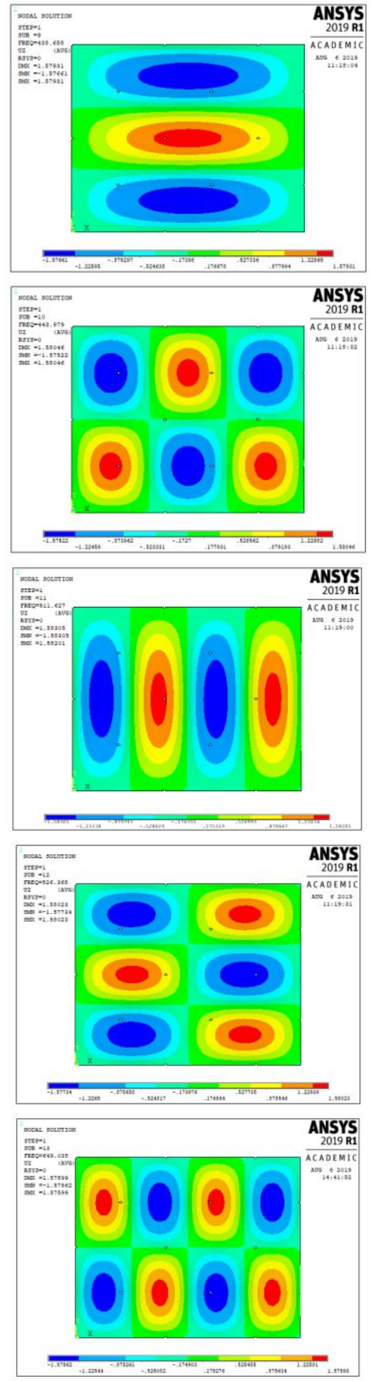


Fig. 19. Set of mode shapes for the first 10 modes of perforated aluminium plate with pitch=100mm

A convergence study has been carried out to understand the behaviour of the perforated plates with the increase in the number of elements of the continuum and varying the pitch of the perforations. The results are tabulated and necessary graphs are shown below.

When pitch=25mm, the convergence is as shown in table 8.

Table 8
Frequencies of the first 10 modes of perforated aluminium plate when pitch of hole=25mm

f(4X5)	f(8X10)	f(16X20)	f(32X40)	f(40X50)	f(64X80)
74.463	74.246	74.24	74.116	74.0533	73.981
161.775	161.413	161.483	161.055	160.865	160.641
211.076	210.488	210.658	210.018	209.731	209.469
299.551	298.128	298.766	297.121	296.363	296.031
308.564	307.218	307.464	306.317	305.858	305.266
439.221	438.466	438.914	437.183	436.581	435.453
449.717	445.069	446.483	442.618	441.813	440.559
512.561	511.382	512.424	510.157	509.347	507.786
529.576	526.864	528.553	525.038	523.83	522.06
655.353	651.141	653.712	646.987	645.357	642.927

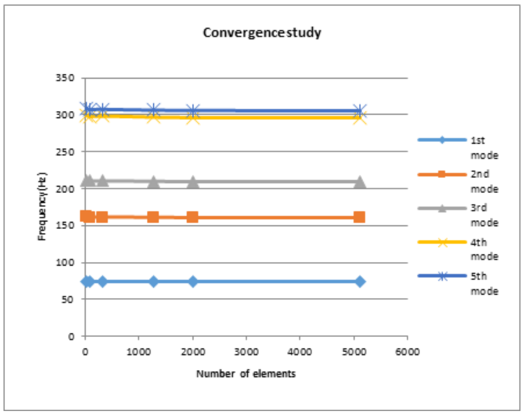


Fig. 20. Chart of convergence study of perforated aluminium plate when pitch=25mm

When pitch=50mm, the convergence is as shown in table 9.

Table 9
Frequencies of the first 10 modes of perforated aluminium plate when pitch of hole=50mm

f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
87.313	82.089	88.598	74.397	74.281	74.2512	74.163
200.744	181.473	192.426	161.827	161.405	161.322	161.054
239.75	217.004	217.565	211.228	210.493	210.362	210
344.283	316.91	318.781	299.631	297.949	297.702	296.835
402.894	342.443	351.645	308.078	306.923	306.656	306.006
510.002	449.517	445.635	441.084	438.145	437.627	436.485
518.848	481.001	480.349	447.874	444.17	443.57	441.812
634.4	555.607	544.396	513.605	511.12	510.423	509.01
671.728	566.482	568.505	531.156	526.343	525.567	523.405
726.762	696.593	701.363	655.981	649.581	648.163	644.972

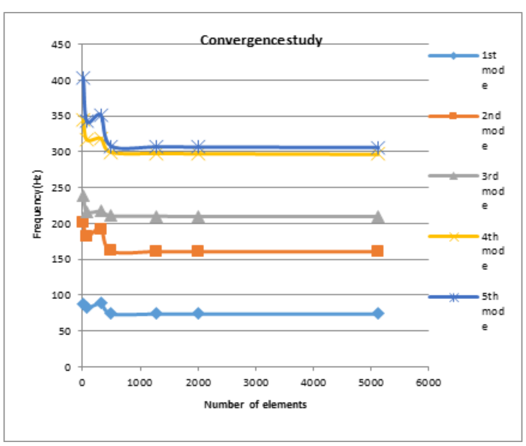


Fig. 21. Chart of convergence study of perforated aluminium plate when pitch=50mm

When pitch=75mm, the convergence is as shown in table 10.

Table 10
Frequencies of the first 10 modes of perforated aluminium plate when pitch of hole=75mm

f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
76.194	75.738	79.436	74.537	82.997	74.3639	74.298
169.318	166.969	173.268	162.245	166.018	161.56	161.345
222.321	219.482	214.825	212.009	225.625	210.704	210.389
322.746	316.327	309.126	300.244	308.534	298.03	297.353
399.038	323.091	325.627	309.419	309.587	307.189	306.571
484.609	467.129	445.387	443.033	449.767	438.527	437.33
507.892	483.299	465.058	449.059	457.134	443.972	442.566
579.459	549.161	539.219	517.723	514.541	511.366	509.955
601.206	579.377	541.772	532.354	541.604	526.284	524.357
756.012	715.791	680.99	658.998	655.778	648.645	646.035

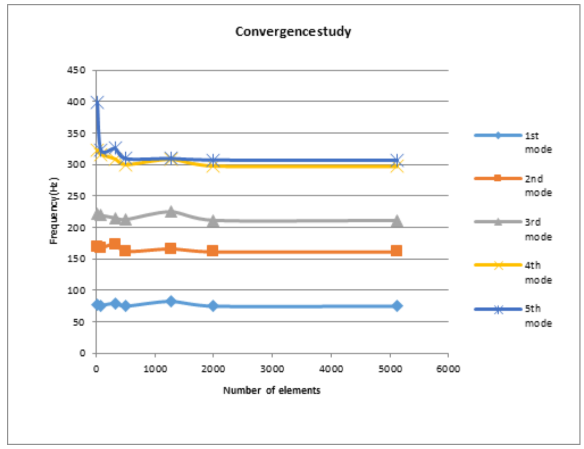


Fig. 22. Chart of convergence study of perforated aluminium plate when pitch=75mm

When pitch=100mm, the convergence is as shown below:

Table 11
Frequencies of the first 10 modes of perforated aluminium plate when pitch of hole=100mm

f(4X5)	f(8X10)	f(16X20)	f(20X25)	f(32X40)	f(40X50)	f(64X80)
94.151	99.567	97.998	93.509	77.896	74.3774	74.315
197.687	185.355	186.34	178.812	168.897	161.585	161.375
256.12	255.122	242.741	236.864	211.038	210.77	210.445
357.664	331.134	326.281	316.783	298.744	298.09	297.402
382.717	337.709	336.159	324.248	316.803	307.207	306.627
516.089	495.455	478.891	462.826	440.334	438.658	437.449
607.206	511.108	485.791	472.485	445.518	443.979	442.596
642.237	573.366	555.429	536.279	520.754	511.627	510.077
713.387	609.705	571.539	563.654	533.145	526.368	524.452
880.124	728.006	698.023	668.283	651.828	649.038	646.147

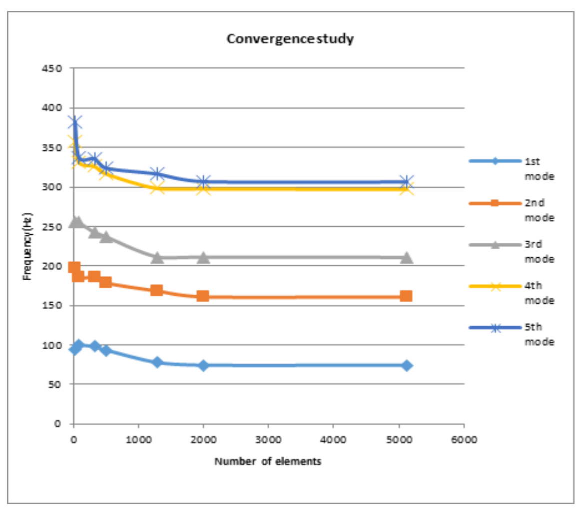


Fig. 23. Chart of convergence study of perforated aluminium plate when pitch=100mm

Hence from the convergence study of the perforated plates with increasing the pitch of the perforations we can conclude that the frequency of the perforated plate converges and tends to become a constant as the number of elements of the continuum increases and becomes consistent. This consistent value of frequency is used to analyse the behaviour of the perforated plate and is compared with the experimental and analytical frequency.

4. Conclusion

From the convention we know that the frequency is directly proportional to the square root of the stiffness of the plate. This convention is again proved from the above modal analysis of perforations of the plate. It is observed that the stiffness of the plate decreases as the perforations increases further reducing the frequency of the plate. Also the consistency of the reduction in frequency is determined by a convergence study.

References

[1] Arthur W. Leissa, Vibration of Plates, 1st ed., Washington D.C., Scientific and Technical Informational Division, 1969.

[2] F. Klimenda, J. Soukup, M. Zmindak, Deformation of Aluminium Thin Plate, Manufacturing Technology, vol. 16, no. 1, pp. 124-129.

[3] S. Chakraverty, Vibration of plates.

[4] Jai Kumar Sharma, Article on Theoretical and experimental modal analysis of Beam.

[5] M. Geradin / D. Rixen, Mechanical vibrations, Theory and application to structural dynamics, second edition.