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Nonlinear Behaviour of Perforated Plate with Lining

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ABSTRACT

Perforated plate with lining has a construction of plate with perforation and a lining plate welded together to form a single plate. This type of plate is used as an acoustic sonar dome. Perforated plate with lining (PPL) is prone to stress concentration and subsequently such structural system falls into the large strain category. Experimental investigation on PPL is carried out in the present study to determine the static deflection of the plate. Numerical method is also followed for geometric nonlinear analysis using finite element method as an iterative interactive procedure. The deflection obtained from the numerical method is 8 per cent less than that obtained from experimental method. From numerical analysis, von Mises stress and maximum principal stress is also estimated to understand about the failure mode characteristics of PPL.

Keywords: Perforated plate with lining, geometric nonlinear analysis.

1. INTRODUCTION

Perforated plate with lining (PPL) is the combination of perforated plate (PP) and a lining plate welded so as to act as a single plate. This type of plate is used extensively in acoustic sonar domes. The perforations in the plate generally have typical stadium geometry which is formed by addition of two semicircles at shorter side of a rectangle. The perforations are arranged in rectangular array m x n with m number of rows along the x-axis (longitudinal) and n number of columns along the y-axis (transverse). Only a few research publications are available in the literature dealing with geometric nonlinear analysis of perforated plate.

Zhao[1], *et al.* carried out geometric nonlinear analysis of plates and shells using linearly conforming radial point interpolation method. However, steel plate shear walls[2] have been used with hysteresis model[3] for nonlinear behaviour of plate with large opening. Pellegrino[4], *et al*. have studied linear and nonlinear behaviour of steel plates under shear loading. Kim and Reddy[5] have brought out novel method based on weighted residual formulations of the equations governing classical and first order shear deformation plate theories. But, literature[6,7] pertaining to perforated plate discusses the nonlinear behaviour by converting material properties to equivalent of solid plates. The nonlinear analysis of perforated plate has been dealt by Paik[8] with a parametric study on perforation dimension using ANSYS[9]. Suneel[10], *et al.* have discussed the ultimate strength analysis based on nonlinear static analysis using ANSYS. Eccher[11], *et al.* have applied isoparametric spline finite strip method to the geometric nonlinear analysis of perforated folded plate.

In the present study, nonlinear behaviour of perforated plate with lining along with perforation and ligament width is investigated using finite element method as an iterative incremental procedure where the displacement of a characteristic point at various load steps will be plotted and inferences are derived from this.

2. GEOMETRIC NONLINEAR ANALYSIS

Geometric nonlinear analysis is often associated with structural systems which show large displacements and/or large strains. The perforations are geometric discontinuities in the plate and result in stress concentration which can cause local failure by yielding. The PPL being prone to stress concentration and subsequently such structural system falls into the large strain category. Geometry of the PPL with stadium perforation is shown in Fig. 1. The plate has been dimensioned considering the requirement of acoustic measurements. This perforated plate has multiple cutouts of stadium geometry with horizontal orientation. The ligament width is 6 mm and is equal in both directions. The PPL is fabricated by welding a lining plate of 1 mm thickness over the perforated plate of 6 mm thick. The PPL is made up of Titanium alloy and its constitutive properties have been given in Table 1. These values are taken from the manufacturer's data sheet. The boundary condition of all the edges fixed, is applied in the analysis considering the practical application.

Geometric nonlinear analysis of the PPL is carried out through a finite element model made with SHELL63 element of the ANSYS software and shown in Fig. 2. The finite element model has 1,41,506 nodes and consists of 1,26,136 elements. The maximum load is kept as 30 kPa and applied in 20 steps with 1.5 kPa as load increments. This maximum load is restricted considering the magnitude of deflection of plate. The deflection (DEF), von mises stress (VMS) and maximum

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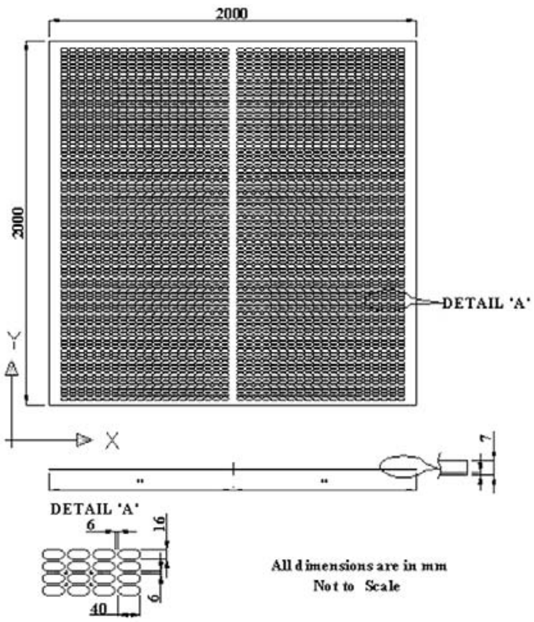

Figure 1. Sketch of perforated plate with lining under study.

principal stress (MPS) are evaluated and shown in Table 2 upto the load of 15 kPa. The load deflection is plotted and shown in Fig. 5.

3. EXPERIMENTAL INVESTIGATION

A PPL shown in Fig. 1 was fabricated with Titanium alloy and used for experimental investigation. This is same as modelled and analysed using finite element method. To apply a uniform load over lining plate of PPL using water as loading medium, a pressure testing chamber is designed and fabricated. The assembly of the plate and pressure testing chamber was ensured for pressure tightness with proper neoprene rubber gasket. Over and above, all the joints are sealed with M-seal. Provision is made for filling up the water using hand pump and for air escape while filling the pressure testing chamber.

For measurement of the pressure in kPa, a calibrated digital-based pressure gauge with resolution of 100 Pa with measuring range upto 100 kPa was used. All the four edges of the plate and pressure testing chamber are assembled with fasteners. In addition C–clamps are used to achieve fixity along the edges where two half of the plates are welded together. Vernier caliper was used to measure central vertical deflection of the PPL. The fixed jaw of the vernier caliper is rested over the perforated plate. Considering the maximum expected deflection, the moving jaw of the vernier caliper is adjusted and placed in position with the support of the L-angle. The photographs of the experimental setup are shown in Figs. 3 and 4. The experimental procedure begins with the filling up of pressure testing chamber with water. The perforated plate with lining is placed over the flange of the pressure testing chamber with lining plate facing the water. A hand pump is attached with the inlet of the pressure testing chamber. With a 'T' connection, provision is given to attach the digital micro pressure gauge. Uniform water pressure is applied over the lining plate area. Considering the pressure testing chamber height, the experiment is started with an initial pressure of

Table 1. Material properties of Titanium alloy

Material	Density (kg/m^3)	Poisson's ratio	Young's modulus (MPa)	Yield stress (MPa)	Ultimate stress (MPa)
Titanium alloy	4500	0.3	1.1 x 10^5	930	1030

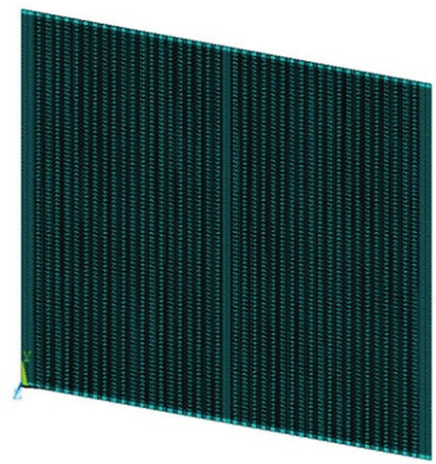

Figure 2. Finite element model of PPL with SHELL63 element.

Figure 3. Experimental setup for load deflection of perforated plate with lining.

Figure 4. Side view of the experimental setup with PPL and pressure testing chamber.

Table 2. DEF, VMS and MPS of PPL from finite element analysis

Values from finite element analysis (SHELL63 element)				Percentage variation between stresses
Pressure (kPa)	DEF (mm)	VMS (MPa)	MPS (MPa)	
0	0	0	0	0
1.5	9.8	77.2	52.6	32
3	13.5	120	88	27
4.5	15.9	153	117	24
6	17.8	182	143	21
7.5	19.4	208	166	20
9	20.8	231	188	19
10.5	22	252	208	17
12	23.1	272	227	17
13.5	24.1	291	245	16
15	25	308	262	15
30	32	449	406	10

3 kPa. Using handpump, pressure is increased at regular increment of 0.5 kPa and the corresponding deflection has been noted after about 5 min on stabilizing pressure fluctuations. This procedure is repeated up to maximum pressure 15 kPa. Two sets of reading are recorded during loading and the load deflection data are shown in Table 3.

4. RESULTS AND DISCUSSION

It was observed that, the perforated plate and lining plate acted together as single entity. The DEF, VMS, and MPS obtained from numerical analysis are given in Table 2. However, to compare the deflection between the numerical and experimental results, the percentage variation was calculated in Table 3. The load deflection from numerical and experimental results were plotted in Fig. 5.

From the finite element analysis, it was found that the initial portion of the load deflection curve is linear and after certain loading, nonlinearity becomes evident. In this study, the linearity changes at a load of 2 kPa and deflection found to be 12 mm. However the nonlinearity is evidently seen at the deflection of 20 mm. The deflection is due to elasticity of the material and vanishes on removal of pressure loading. However from the experiment, it is seen that the linearity changes at a load of 7.5 kPa and the percentage variation between finite element analysis and experiment is 7.6 per cent. From Table 2, it is also noticed that the von Mises stress is higher than maximum principal stress by 32 per cent initially and thereafter the deviation decreases to 10 per cent.

From Fig. 5 through numerical analysis, it is observed that even though deflection is five times compared to the thickness of PPL for the pressure load of 30 kPa, the stress induced in the plate is only 50 per cent of the yield stress of the material. It is evident from the geometric nonlinear analysis that the PPL of this geometric configuration falls under the category of large displacement/large strains.

Table 3. Variation in percentage of deflection from experiment and finite element analysis

Experimental Values				FEA	Percentage variation between experiment & FEA
Pressure (kPa)	Deflection (mm) Trial 1	Deflection (mm) Trial 2	Average DEF (mm)	DEF (mm)	
0	0	0	0	0	0
3	8	8.7	8.35	13.5	61.68
4.5	13	13.5	13.25	15.9	20
6	19.2	19.6	19.4	17.8	-8.25
7.5	20.8	21.2	21	19.4	-7.62
9	22.5	23	22.75	20.8	-8.57
10.5	23.5	24.1	23.8	22	-7.56
12	24.6	25.7	25.15	23.1	-8.15
13.5	25.6	26.8	26.2	24.1	-8.02
15	26.5	27.5	27	25	-7.41

Deflection obtained from the experiment is higher than the numerical method except for the first two readings as appeared in Table 3. The high percentage variation may be due to initial air trap in the pressure testing chamber. Neglecting these two readings, the variation in deflection is within 8 per cent.

5. CONCLUSIONS

Based on the experimental and numerical study for the perforated plate with lining of the present configuration, the following conclusions were made.

- From the numerical analysis and experiment, the nonlinearity behaviour of the PPL of this configuration is noticed and the percentage variation with reference to experiment is 7.6 per cent.
- It was observed that the load deflection curve of the experiment and numerical analysis has similar trend and follows same pattern especially after the airtrap is released which is evident from the graph shown in Fig. 5. Hence the method of geometric nonlinear analysis of PPL is established along with the experiment.
- The experiment was not possible in all cases considering the time and cost involved, hence a numerical procedure

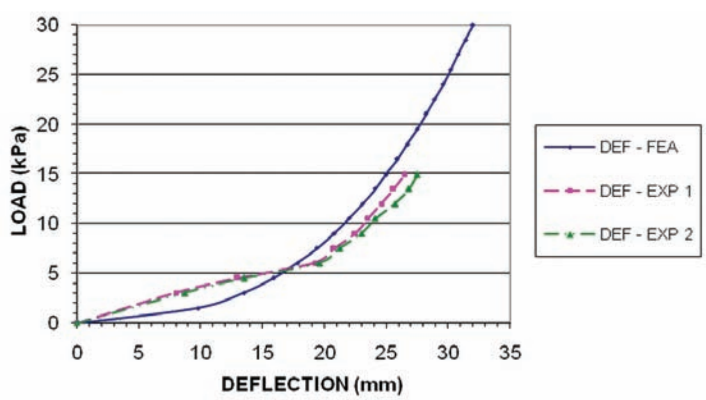

Figure 5. Load deflection curves of PPL from experiment and numerical analysis.

method was established to study nonlinear behaviour of PPL.

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