Structural Analysis for Optimization of Stairs in off Road Agricultural Machinery

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Abstract

Numerous design for steps, gangways or access platforms are found in off road vehicles like agricultural machinery. These stairs are usually sheet metal weldments or parts with complicated formed features. Cost is one of the major factor in any industry. Hence as parts or weldment grows in complexity, its cost also raises and for the same reason structural optimization has gained importance in recent years.

In this study a static structural analysis is performed on a perforated plate using finite element analysis software ANSYS 16.2 and the results were validated with experiment.

The aim was to identify if such perforated plates can be a potential replacement for weldments which can result in cost and complexity reduction.

The variation in Finite element analysis and experimental results is found to be around 11% and the plate tested had a maximum equivalent stress within the yield stress limit of the material considered. Hence perforated plate can be used to convert step weldment into a bolt on assembly, thereby simplifying the design.

Keywords — perforated plate; stress analysis; sheet metal; optimization.

I. INTRODUCTION

Light weight structures have gained high prominence in recent years. Most of the stairs or gangways leading to platform in agricultural machinery are weldments. It usually consists of three to four formed sheet metal plate welded to side plates or teethed sheet metal strips combined to form a weldment.

As manufacturing weldments are costly, there is a need to simplify the design. The benefits of converting a weldment into a bolt on are, process complexity reduction, elimination of weld labor and fixture cost, better serviceability, reduction in manufacturing and assembly time.

One of the alternative to weldment structure is to use a bolt on design with perforated plates. Perforated sheet metal plates has manually or mechanically punched holes where the hole shapes can be round, square, triangle, diamond, oval, hexagonal etc. It is generally advisable to have the hole size larger than material thickness.

The use of perforated thin steel plates is very common in many engineering applications [1]such as platforms in various agricultural and earth moving machines, offshore platforms, ship decks and hulls, box sections of bridge girders and air craft industries. Perforations are provided for dirt drain, inspections, maintenance and majority of times to reduce weight of structure.

The aim of this study is to analyse the behaviour of a perforated plate under vertical loading and to determine if this plate can be used to convert a stair weldment into simple bolt on design for cost and complexity reduction.

II. LITERATURE SURVEY

Various studies have been carried out related perforated plate with lateral loads as well as axial loads.

Vimal M N [2] studies the structural behaviour of perforated plate with circular, hexagonal and slotted perforation by applying a uni axial tensile load.

M. Aydin Komur [3] investigated the elasto-plastic buckling behavior of simply supported square and rectangular thin steel plates having elliptic cut-outs.

Jinho Woo [4] investigated stress concentration of perforated plates with cur out, orientation of cut out and bluntness.

EmanueleMaiorana [5] analyzed linear buckling of square and rectangular plates with circular and rectangular holes in various positions subjected to axial compression and bending moment.

D.B.Kawadkar [6] studied the stress concentration in plate with various cutouts and bluntness with different cutout orientation.

J. Rezaeepazhand [7] conducted analytical stress analysis of plates with different central cutout. Particular emphasis was placed on flat square plates subjected to a uni-axial tension load.

Arz Yahya Rzayyig [8] studied the effects of two cutouts on the stress concentration factor, maximum stress and deflections in perforated clamped rectangular plates.

O.R. Nandagopan [9] investigated perforated plate with lining to determine the static deflection of the plate.

D. J. Bynum [10] investigated the experimental stress and deflection data for thick, circular, simply supported plates, containing circular transverse perforations in square motif, under uniform lateral loading.

III. GEOMETRY AND MATERIAL PROPERTIES

Geometry of the specimen for study is shown in Fig 1.

Assumptions:

- Plates size 250mm x 250 mm, 3mm thick
- Hole pattern is square
- Bolted on two sides

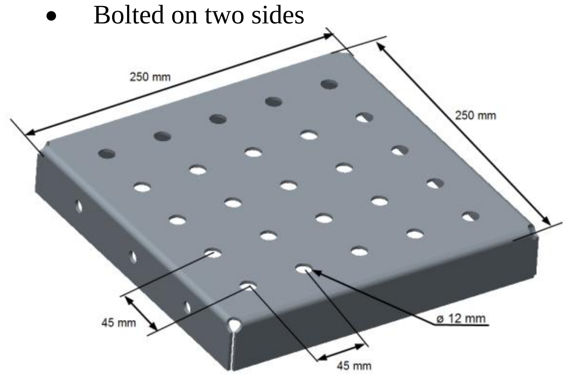


Fig. 1. Geometry

Material properties:

The material specifications of the specimen is listed in table 1 [11].

TABLE I

Material	MS IS 513 CR2
Yield Stress	240Mpa
Density	7.85e-6 kg/mm3
Modulus of elasticity	210GPA
Poisson's ratio	0.3

Load: General weight for large operator 114.1Kg [12] with a bag of seed 25Kg.

Design load considered is 278 Kg (2724N which includes factor of safety-2) [13].

IV. FINITE ELEMENT MODELLING

ANSYS 16.2 is used to carry out finite element analysis and design of experiments [14].

A. Finite element modelling:

The finite element model details are as mentioned below.

Meshing element type is 4 node quad shell 181
Mesh size is 1mm
Node population count 186932
Element population count 92331
Design load of 2724 N applied centrally on a surface of 145mm diameter
Load behavior is taken as Rigid which resembles the practical case
Boundary condition- blotted on two faces with three bolts and hence the holes surfaces were fixed.

Iteration1

First iteration was carried out with the perforated plate having flanges at the bolt on sides only. Figure 2 shows the stress distribution.

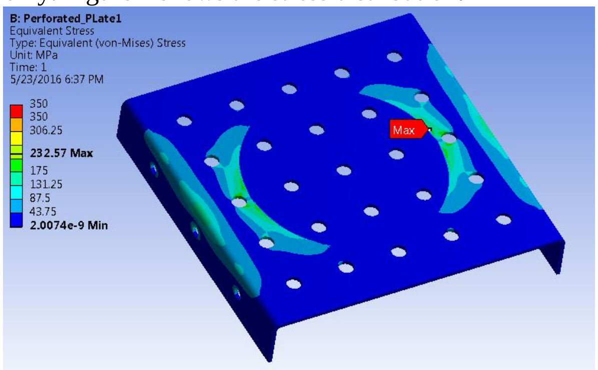


Fig. 2. Perforated plate with 2 flanges

Iteration2

Flanges are added to other two edges for strength as shown in Figure 3.

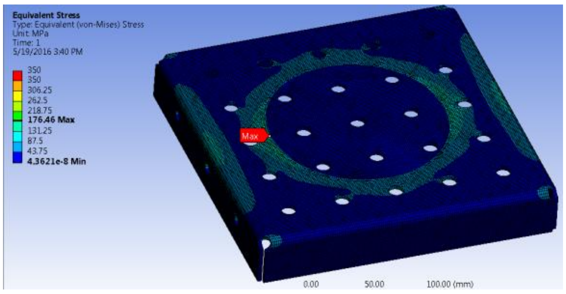


Fig. 3. Perforated Plate with 4 Flanges

Iteration 3

As per the standard [13], the steps and platforms must have good anti slip property. Therefore embossing was added to the perforated plate and FEA was carried out as shown in below Figure 4.

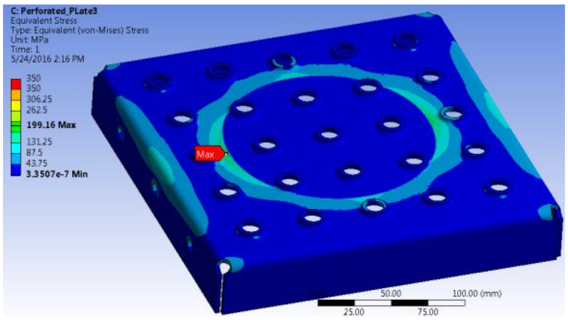


Fig. 4. Perforated Plate with Embossing

Strain gauge location is picked on the basis of vector principal strain direction shown in Figure 5.The maximum strain location happens to be at the point below the load which is impractical to gauge. So the next high strain area (close to bolted side) was chosen as gauge location for correlation.

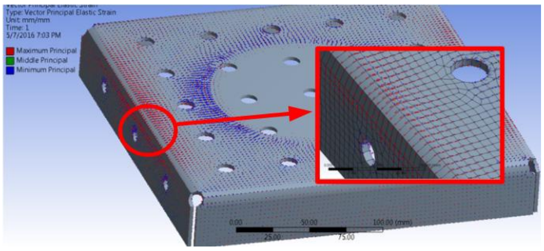


Fig. 5. Vector Principal Strain Direction

V. EXPERIMENTATION

A. Specimen and Gauge location

Experimentation was carried out for iteration 2 model as it was easily manufacturable.
Figure 6 shows the specimen (3mm thick, 12mm diameter hole, 25 holes, 45mm x 45mm spacing) and the gauge locations.

Two gauges were laid, one on the side near the bolt on faces as per FEA vector principal direction and the other underneath the load.

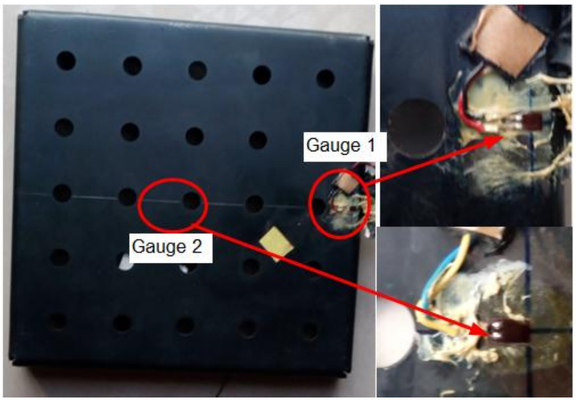


Fig. 6. Specimen and Gauge Location

B. Experimental Set up and Procedure

The specimen was held between the side plates (fixture) as shown in the Figure 7. The load is gradually varied from 50kg to 400 kg in increments of 50 using a hydraulic actuator.

A load cell and a load plate (145mm diameter plate to replicate FEA model) is placed on the actuator. The gauge readings are recorded through eDAQ. Figure 8 shows the output format.

Fig. 7. Fixture And Experimental Set Up

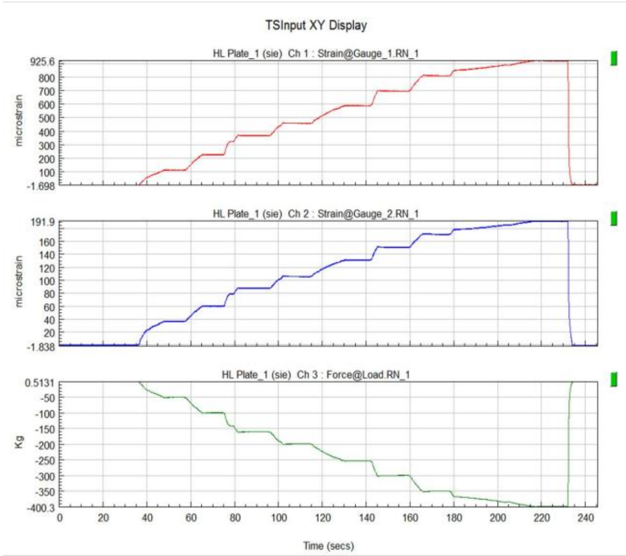
Fig. 8. E-DAQ Output File

VI. RESULTS AND COMPARISIONS

FEA of the specimen was carried with 8 steps load ranging from 50 Kg to 400 Kg with increment of 50, 278 kg being the design load.

Maximum equivalent stress from FEA on iteration 1 at 278Kg is 232.5Mpa.

Maximum equivalent stress from FEA on iteration 2 at 278Kg is 176 Mpa



Maximum equivalent stress from FEA on iteration 3 at 278Kg is 199 Mpa

Strain comparison for gauge1 between FEA and experiment for iteration 2 is shown in figure 9. Gauge 2 was ignored as the value was negligible.

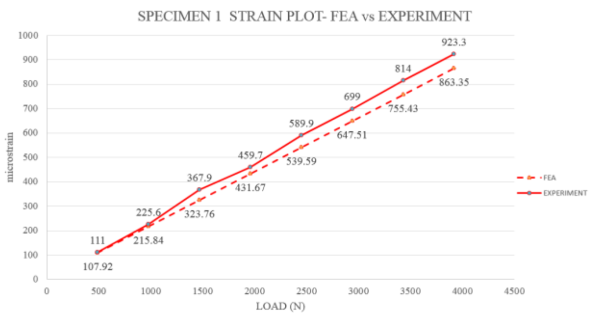


Fig. 9. FEA vs Experimental results for Iteration 2

VII. CONCLUSION

Experimental validation was performed for perforated plate without embossing and the maximum variation between FEA and experimental values are approximately around 11%. Considering this variation, the maximum equivalent stress on the plate with only two flange exceeds the acceptance criteria. The stress on second iteration (with all four flanges) is 176 Mpa which is within the acceptable yield limit.

The maximum stress on embossed perforated plate from FEA is 199 Mpa and considering the variation of results between FEA and experiment, the maximum stress is 219Mpa which is still within the acceptable limit (Table 1).
Hence the perforated plate with embossing can be a potential solution which can used to reduce the complexity of design.

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REFERENCES

[1] Manoj S. Kulkarni , S. Y. Gajjal "Review of Sheet Metal Forming Analysis" , SSRG-IJME – volume 2 Issue 1–January 2015.

[2] Vimal M N, "Design And Structural Analysis Of Perforated Sheet Metals", International Journal of Advanced Scientific and Technical Research, Issue 3 volume 4, July-August 2013

[3] M. Aydin Komur,"Elasto-plastic buckling analysis for perforated steel plates subject to uniform compression", Mechanics Research Communications 38 (2011) 117–122O.

[4] Jinho Woo1 and Won-Bae Na1, "Effect of Cutout Orientation on Stress Concentration of Perforated Plates with Various Cutouts and Bluntness" International Journal of Ocean System Engineering 1(2) (2011) 95-101

[5] EmanueleMaiorana,CarloPellegrino, ClaudioModena, "Elastic stability of plates with circular and rectangular holes subjected to axial compression and bending moment", Thin-Walled Structures 47 (2009) 241–255

[6] D.B.Kawadkar, Dr.D.V.Bhope, S.D. Khamankar "Evaluation of Stress Concentration in Plate with Cutout and its Experimental Verification", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 5, September- October 2012, pp.566-571

[7] J. Rezaeepazhand, and M. Jafari, "Stress Analysisof Perforated Composite Plates, Composite Structures", 71 (3-4) (2005) 463-468.

[8] Arz Yahya Rzayyig, 'Numerical study of stress concentration in tensioned plate", Vol 19, No 4 (2012): Tikrit Journal Of Engineering Sciences –*MechanicalEngineering*

[9] R. Nandagopan, S. Ranjith Kumar, M.R. Rajesh, K. Manoharan, and C.G. Nandakumar, "Nonlinear Behaviour of Perforated Plate with Lining" Defence Science Journal, Vol. 62, No. 4, July 2012, pp. 248-251

[10] D. J. Bynum, M. M. Lemcoe, "Birefringent-coating analysis of laterally loaded perforated plates", Experimental Mechanics June 1963, Volume 3, Issue 6, pp 140-147

[11] http://bis.org.in/sf/mtd/MTD4(4670).pdf

[12] ISO 3411 physical dimensions of operators

[13] ISO 4254-1:2013 - Agricultural machinery - Safety -Part 1

[14] Ansys mechanical's user guide