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Analysis of Elastic Peak Stress at Radial Crosshole in Square Block

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***Abstract*—A square block with crosshole is modelled using ANSYS Finite Element Analysis software package to investigate peak stress location under internal pressure. The square block model is meshed with multiple type of element in which will provide faster solving time and uses less computational resource. The use of multiple elements can lead to distortion at the transition area and is considered in the analysis. SA-372 steel material property is selected for the analysis with internal pressure is applied on the main bore and crosshole in the square block. The elastic analysis result of the square block model with crosshole shows that the peak stress is occurred at the tip of the sharp intersection on the inner part of the block. The location of peak stress occurs at the sharp intersection is expected at the assumed area, due to discontinuity caused by the crosshole on the square block structure. The peak stress located at the sharp intersection will caused the material to fail which can lead to shorter fatigue life. The result thus can be used for engineers and designer to consider maximum stress location in block with discontinuity.**

Keywords—Finite element analysis; ANSYS; pressure vessel; square block; crosshole; stress concentration; cross bore.

I. INTRODUCTION

Pressurised system uses a number of mechanical components that holds pressurised liquids or gases within a closed container. The component is designed to hold pressure from internal or external or both internal and external pressure. There is a wide range of pressure related equipment that is used in our daily life, from using an electric kettle to storing of fuel at petrol station. ASME Code, BSI PD5500 and EN 13445 are the design codes related to pressurised system component in particular pressure vessel. The codes have placed safety of pressure vessel operation in highest standard to prevent any untoward incident that will cause loss of precious time, money and most importantly loss of life. Analysis on the pressure vessel design and structure must be considered so that it can prevent any accident and at the same time it can maximize the life of the pressure vessel. A pressure vessel can be designed by using two methods which is; design by analysis and design by formula **[1]**.

Usually, in pressure-related component design will accommodate nozzle and crosshole that will create discontinuity on the pressure vessel shell. This discontinuity will create peak stress or local stress concentration that will give rise to fatigue cracking and brittle fracture which leads to failure of pressure vessel structure/component **[2]**. Stress is described as limiting process and in general, stress concentration is associated with peak and gradient around the peaks of the stress component. Pressure vessel that is manufactured with nozzles, and holes will create a high peak stress concentration due to reduced pressure carrying capacity compared to pressure vessel without nozzles and holes **[3]**. The significance of stress concentration is based on the theory of elasticity.

Theoretically, this discontinuity will create stress riser at the intersection in between the main bore and crosshole/bore and subsequently will create a local stress concentration **[4]**. The changes are assumed to reduce the stress concentration which will lead to increased of pressure vessel life. Elastic stress concentration at radial crosshole in pressurised thick cylinder studied by Comlekci, Mackenzie and Wood **[5]** investigated the stress concentration at radial crosshole in pressurised cylinder by using numerical and graphical form **[5]**. Result from **[5]** analysis shows that the location of maximum stress does not generally occur at the junction between the bores, but a small distance up from the intersection junction. Findings from **[5]** result is contradict to the assumption that stress concentration will located at the crosshole and main bore junction.

Kihiu, Rading and Mutuli investigated stress distribution and stress concentration in a chamfered crosshole – main bore intersection area **[6]**. The cylinder for this study is assumed to be close end and thrust load is applied on the cylinder thickness to simulate the load. This study involves several thicknesses and chamfer radius ratios and the result shows that high stress concentration on a plain or sharp intersection, when chamfer is introduced to the sharp intersection the stress concentration is lower than plain intersection. The study also recommended that this analysis can be applied to thin pressure vessel cylinder construction **[6]**.

20 noded and 8 noded elements are used to model a thick cylinder for stress concentration analysis at crosshole in thick cylindrical vessel analysis by Makulsawatudom, Mackenzie and Hamilton **[7]**. The research is explores whether the stress concentration presence depends on the size, shape and location of the crosshole **[6]**. Three models are considered for the analysis which is plain or sharp intersection model, chamfered crosshole-main bore junction and blend crosshole junction. Result from the analysis shows that, minimum peak stress is recorded at the sharp intersection of the plain model and by introducing chamfer and blend radius, the stress concentration at the intersection are reduced but at the same time higher stress is recorded occur elsewhere in the blended and chamfered region **[7]**. Result analysis from **[6]** can be compared to the work done by **[7]**, where by employing chamfer intersection can reduce the stress concentration between the crosshole and main bore area.

A study of stress concentration in square block shows that, in the case of square block, the maximum stress is located in the diagonal plane and in the crossbore place, the stress at the inner bore is significantly lower due to bending effect **[8]**. An elliptic crossbores in a rectangular block analysis presented by Badr **[9]**, found that the hoop stress for elliptic crossbores in a rectangular block are lower than hoop stress obtained from circular crossbores without consideration of the crossbores intersection. An Optimal pressure vessel shape design to maximize load analysis are done by J, Middleton and J, Petruska which explores the possibility of optimum shape design of axisymmetric bodies and how to establish geometrical changes effect load behaviour **[10]**. In referring to the work done by **[10]**, the maximum elastic stress concentration is set as the design objective and several parametrical geometries of the pressure vessel head are varied throughout the analysis. The result from **[10]** shows that stress concentration peaked at the pressure vessel head and by increasing the thickness of the pressure vessel head and pressure vessel head height will result in the reduction of stress concentration. In this study, elastic stress concentration due to crosshole in a square block is investigated.

I. Methodology

A. Element Modelling

Any given component in real world is a complex structure if all the detail and sophisticated geometry are to be considered. Simplification of the model is one of the ways either designers or engineers can employ in the finite element model. Simplification involves removing some unnecessary detail that would not affect much on the specified analysis.The block with crosshole model uses eight node hexahedral elements, 20 node hexahedral elements and 10 node tetrahedral elements. The simplest 3-D hexahedral element is the eight noded hexahedral elements, with having eight corner nodes with three degree of freedom per node where this type of elements is not a constant strain element as these higher order terms will enable the strain in the element to linearity as a function of coordinates, thus will performs better especially under bending loads. The concept of 20-node hexahedral elements is where an eight node hexahedral elements are added with one node each per edge, and this will result a 20-node hexahedral element. This element is a complete form of quadratic function and with addition of cubic and higher order terms and solving with a model using 20-node hexahedral are time consuming and computationally intensive. The meshed square block model is illustrated in Figure 1.

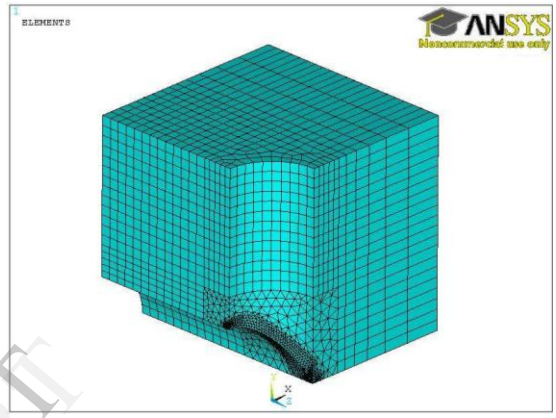

Figure 1: Square block model in element view

The use of multiple elements for the analysis can reduced solving time and computational resources, therefore the element transition between elements is considered in the analysis. A study performed by C. K. Choi et al, stated that the transition of element order does not produce zero energy and distorted element shape and will not influence the general accuracy level in the result produced **[11]**. Therefore, the accuracy located at the transition can be neglected. The element transition is shown in Figure 2.

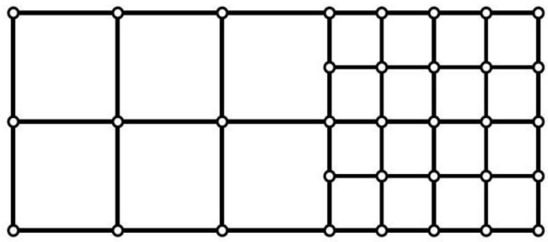

Figure 2: A 2-D example of element transition area

B. Material Properties

A linear elastic material is selected for this research which is represented by using SA – 372 steel, which has a Poisson's ratio (ν) of 0.29, a Young's modulus

(E) of 209 kPa and yield strength (σ_y) of 450 kPa. This type of material is used widely in construction of pressure vessel or component in pressurised system.

C. Boundary Condition

The square block is modelled only a quarter of the original model and symmetry boundary condition can be applied on the entire model. By taking advantage of symmetry boundary condition, the size of model analysis will be reduced by at least by a quarter compared to analysis of full model. With reduction of analysis size, computer resource and solving time can be reduced tremendously if symmetry boundary condition is applied. ANSYS Academic version is build with a limit of 32000 number of element can be created, it is impossible to create finer mesh or use higher order element for full model with using symmetry boundary condition. But by using symmetry boundary condition, model can be created with finer mesh and uses higher order element that will produce much more accurate result in contrast with coarsely meshed full model.

D. Model Configuration

The block is represented by a quarter section model. The quarter section geometry consists of width, a = 200 mm, height, b = 200 mm and length, c = 200 mm. The compressed air component contains two bores that crisscross each other at the middle of the block model with 90^0 apart. Both holes are represented with main bore (r_{c1}) =50mm and crosshole (r_{c2}) = 50mm respectively as illustrated in Figure 2. Due to the complexity of the model, several small and simple volumes are created so that it is easier to mesh using hexahedral element. Two types of element are used for this particular model which uses 20 node hexahedral elements and eight node hexahedral elements. The use of higher order element at both holes area is vital, because as discuss earlier, model utilising higher order element will produced accurate result from the analysis compared to lower order eight node elements. A tetrahedral element mesh is created at area where two bores are meet due to complexity of that particular area to mesh with the hexahedral element and the remaining volumes that has been created are meshed using eight node hexahedral element.

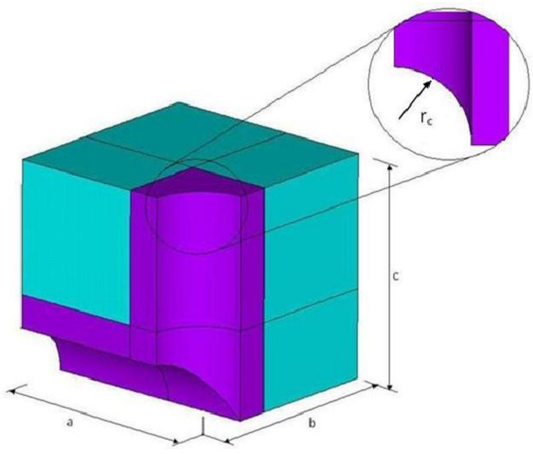

Figure 3: Model of a square block with radial crosshole

II. RESULT

The square block model in ANSYS is a simplified model of a component in pressurised system being applied with internal pressure (P_i). The amount of pressure applied in the block is at 46.2 kPa. The model is plotted using von Mises equivalent stress contour plot so that the maximum stress (σ_{emax}) can be determined and the σ_{emax} is 229.074 kPa concentrated at the intersection in between the main bore and crosshole as shown in Figure 4. The σ_{emax} is positioned just about on the tip of the intersection between the two crossbores. The pressure also caused the block to displace by 33.115 mm from the initial model.

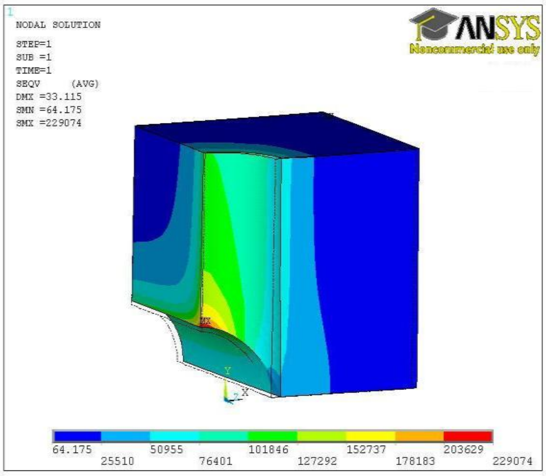

Figure 4: Stress distribution on the square block

The stress distribution on the block model is shown in Figure 5. Comparing the result obtained from the analysis shows that the location of peak stress is similar with study performed by Comlekci et al, Kihiu et al and Makulsawatudom et al, even though their models are based thick cylinder design. This primarily due to the main bore and crosshole construction inside the model is comparable to the model that is being studied. Peak stress location on the block model is mainly caused by sharp intersection between the main bore and crosshole where both main bore and crosshole meet. Apart from that, discontinuity is also part of the reason where the peak stress occurred. Discontinuity caused the block model to lose some of its pressure bearing capability. The discontinuity on the block model is caused by the crosshole introduced inside the block model in reference with **[4]**.

The stress distribution indicated in Figure 4 and 5 show that higher stress intensity occurred close to the main bore and crosshole in comparison with the outer surface of the block. The high stress distribution on the inner part of the block model is caused by the resistance of the main bore and crosshole surface against the pressure applied on both of the surface.

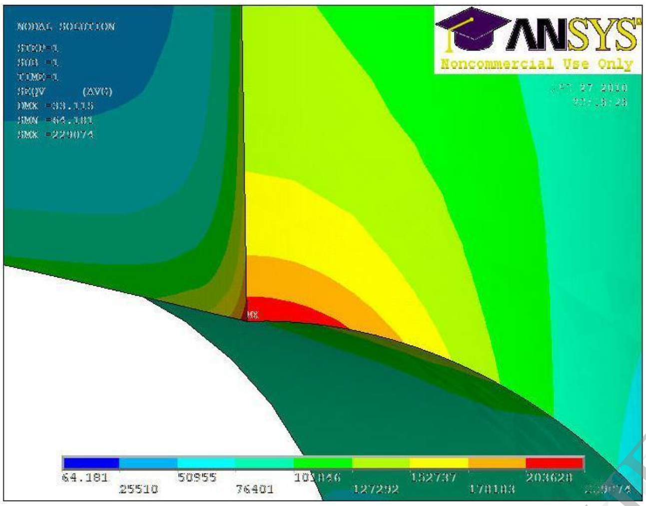

Figure 5: Close up view of peak stress location

III. CONCLUSION

The stress distribution indicated in the result shows that peak stress located precisely at the junction between the main bore and crosshole. The result produced from the analysis is comparable with **[4]**, **[5]**, **[6]**, and **[7]** although most of the analysis is based on thick cylinder model. Therefore, it can be concluded that model arrangement (thick cylinder or square block) does not influence the peak stress location at a two bores junction. The crosshole introduced in the square block model plays a big role in determining the maximum stress location. The crosshole caused the square block to lose some of its load bearing capability where the maximum stress probably occurred. Further stress concentration factor (SCF) analysis on the different main bore-crosshole ratio against maximum stress concentration is needed.

IV. REFERENCES

[1] PD5500:2012, "Specification for unfired fusion welded pressure vessels", British Standard Institution, UK, 2012

[2] Gupta, Shyam R.,Vora, Chetan P., "A Review Paper on Pressure Vessel Design and Analysis", International Journal of Engineering Research and Technology, Vol.3, Issue 3, pp 295-300, 2014

[3] Pravin Narale, P.S. Kachare , "Structural Analysis Of Nozzle Attachment On Pressure Vessel Design," International Journal Of Engineering Research And Application,Vol.2,pp 1353-1358, 2012

[4] Henry H. Bednar, P.E., Pressure Vessel Design Handbook, van Nostrand Reinhold Company Inc., 1986

[5] Comlekci, T., Mackenzie, D., Wood, J., 2007, Elastic stress concentration at radial crosshole in pressurised thick cylinders'' J. Strain Analysis, 42, pp. 461-468

[6] Kihiu, J.M., Rading, G.O., Mutuli, S.M., 2007 ''Universal stress concentration factors and optimal chamfering in cross-bored cylinder,'' International Journal of Pressure Vessel and Piping, 84, pp. 396 - 404.

[7] Makulsawatudom, P., Mackenzie, D., and Hamilton, R., 2004 ''Stress concentration at crosshole in thick cylindrical vessels'' J. Strain Analysis, 39, No. 5, pp. 471 – 481

[8] Dixon, Ricky D., Peters, Daniel T., Keltjens, Jan G.M., 2004 "Stress concentration factors of cross-bores in thick walled cylinders and block" J. Pressure Vessel Technology, 126, pp 184 - 187

[9] Badr, Elie A., 2006 "Stress concentration factor for pressurised elliptic crossbores in block" Int. J. Pressure Vessel and Piping, 83, pp 442 -446

[10] Middleton, J., Petruska, J., 1986 ''Optimal pressure vessel shape design to maximize limit load'' Eng. Comput., 3, December.

[11] Choi, C.K., and Park, Y.M., 1989, "Non-conforming transition plate bending elements with variable mid-side nodes", Computer and Structures, 32, No. 2, pp. 295-304.