Finite Element Analysis of Stresses Caused by External Holes in Hydraulic Cylinders

A.N. El Kholy*, M. A. Kamel**, and M. O. Mousa***,

Teaching assistant *, Assoc. Professor**, Professor***,
Production and Design Depart, Faculty of Engineering,
Minia University, Egypt

Abstract. This paper evaluates simulations of holes in the wall of cylinder. The stresses generated incrementally in Finite Element Method under internal pressure. The holes, which can consider as a stress raiser, established in external surface. The effect of the hole depth, which varied between 0.5 to 4.5 mm, and the hole diameter, which varied between 1 to 2.5 mm, on the generated stresses are presented. It was found that, the hoop stress increase due to increase of the hole parameter, diameter and depth. Moreover, the characterizations of notch used to determine the maximum stress limit.

Keywords: Finite Element Analysis, Hoop stress

1 Introduction

Design of equipments, hydraulic cylinders, pressure vessels, and pipes carrying high pressure must accept a certain levels of performance. In general, the pressurized cylinders are working at allowable pressure, which means that the system should be safe and durable. The assurance of safety and durability is necessary to keep away from deformation of the cylinders. Additionally, cracking due to internal pressure in the cylinders must avoid or limited.

Analysis of pressure vessel and hydraulic cylinder may have a variety of phases, [1]. Mechanical loads, elastic and deformation analysis, are the most common phase may be applied. The ASME codes suggested two ways of strength design of pressurized cylinders. The design was applied by using by formulae and design by using analysis. An analytical solution for the stress, strain and displacement fields in an internally pressurized thick-walled cylinder of an elastic strain-hardening plastic material in the plane strain state presented, [2]. The solution has given explicit expressions for the stress, strain and displacement components.

The internally pressurized thick-walled cylinder problem was studied, [3]. An analytical solution for elastic perfectly plastic cylinders under internal pressures was exacted solutions. The solutions based on classical elasticity and plasticity theories. However, the size of the cylinder was involved only in non-dimensional forms. The solution applied not only for the larger elastic domain, but also for the localized plastic domain near the inner surface. The internally pressurized thick-walled was

studied using no small micro length scale, [4]. The theories of the strain gradient elasticity, which containing scale parameters of the internal material length, can be capable of explaining microstructure, [5]. The structures investigated under conditions of double acting forces. It found that, the effect of the structure can be observed at the micro scale.

The stress concentration factor for an internally pressurized cylinder containing a radial U-notch along length studied, [6]. The external to internal radius ratio has considered and the notch radius to internal radius ratio had a constant value. The study based on the determination of the nominal stress for un-notched cylinder and the generated stress due to notches using finite element method. The elastic stress concentration factor for a pipe with local wall thinning considered using three-dimensional elastic finite element analysis, [7]. The stress concentration factors tabulated for practical use.

Local deformation field and fracture characterization of V-notch were studied experimentally using coherent gradient sensing, [8]. The governing equations that relate to the coherent gradient sensing measurements and the elastic solution at V-notch tip were derived in terms of the stress intensity factor, material constant, notch angle and fringe order. The stress factor obtained from coherent gradient sensing measurements shows a good agreement with finite element results. A three notch sizes of the same stress concentration factor considered, [9]. The high cycle fatigue limit stress can be corresponding to a life of 106 cycles was experimentally determined at a stress ratio of 0.1 and a frequency of 25 Hz at room temperature. The stresses calculated using finite element analysis and the specimens were analyzed using scanning electron microscopy. It found that, the notch affected by a combination of the stress and plastic strain fields at the notch tip.

Elastic-plastic analysis of the stress-strain state approximately a hole in a thick walled cylindrical pressure vessel studied, [10]. The investigations have been inspired by the phenomenon of ductile fracture can be observed in a high-pressure reactor. Using finite element calculations, different failure criteria were proposed to aid design and control of high-pressure vessels with piping attachments. The local stress was distributed near the hole results in a specific failure of the vessel. A plastic zone appears near of the internal cylinder surface and propagates along the hole side. The vessel-unloading can caused local reverse plasticity, which leaded to progressive ductile fracture in this zone.

The slant fracture phenomenon studied numerically by adopting a recently developed damage plasticity theory, [11]. The numerical integration algorithm presented for small strain case. Three applications of different loading conditions had shown to illustrate its effectiveness in predicting ductile fracture. The numerical solutions are in good agreement with the experimental observations.

2. Finite Element Model Creation

A Finite Element package used to predict the effect of surface texture parameters on the generated stresses in the thick-walled cylinder under the action of internal

pressure. The investigated object is an extruded thick-walled cylinder of stainless steel grade 630. The details of the cylinder dimensions and the mechanical properties shown in the following table, [12]:

Cylinder internal diameter	**84 mm**
Cylinder external diameter	**114 mm**
Cylinder height	**335 mm**
Internal pressure	**12 MPa**
Modulus of elasticity "E"	**196 GPa**
Poisson's ratio "μ"	**0.3**

The stresses generated incrementally in Finite Element Method under internal pressure. The holes, which can consider as a stress raiser, established in internal surface. The effect of the hole depth, which varied between 0.5 to 4.5 mm, and the hole diameter, which varied between 1 to 2.5 mm, on the generated stresses are presented. In addition, the effect of excess internal pressure had studied, where an increase of 5%, 10%, 20%, 30% and 40% of the nominal acting pressure is considered. Figure 1 shows a construction drawing for the cylinder.
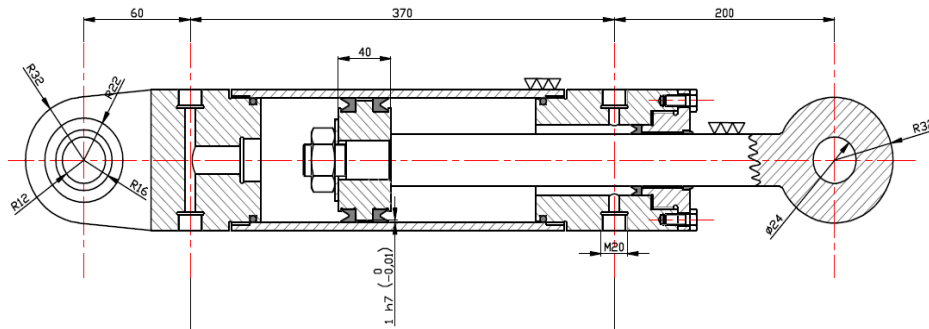
Fig. 1 Assembly drawing of hydraulic cylinder, [12]

For this study, several methods were tested. Finite element analysis offers many ways to analyze structures; it requires an understanding of the program and subject had modeled. If the operator does not use the correct model, time is wasted and more importantly, the data is useless. Element types included shell and solid elements. In the case of shell elements, linear and quadratic elements compared. Models tested included two-dimensional models "Model I". Contact elements were then tested to determine how best to employ them to determine contact points between nodes.

According to the simulation of non-notched thick-wall cylinder using finite element method (FEM), a good agreement has detected between the results and that obtained from analytical solution. The radial stress introduced in the cylinder due to internal pressure of 12 MPa, varies between zero at the outer surface and -11.95 MPa at the inner surface of the cylinder with an error of 0.25%. The hoop stress introduced in the

cylinder due to internal pressure, varies between 40.48 MPa at the inner surface with an error of 0.05% and 28.48 MPa on the outer surface of the cylinder with an error of 0.07%.

The results of FEM show the stresses at any point in two perpendicular directions, it is found that the values of the calculated stress at the horizontal direction (i.e. at Y=0) have a good agreement with the analytical values that introduced from the equations. Here, the radial stress is equivalent to the obtained values in the x-direction while the tangential stress represented by the results in the y-direction. Moreover, it is important to notice that, the values in x- and y-directions at the horizontal section ($\Theta=0^{o}$, Y=0) is similar to the values of the stress in y- and x-directions at the vertical section ($\Theta=90^{o}$, X=0) receptively. Figure 2 shows the stresses and the mesh of a quarter of the cylinder under internal pressure of 12 MPa.
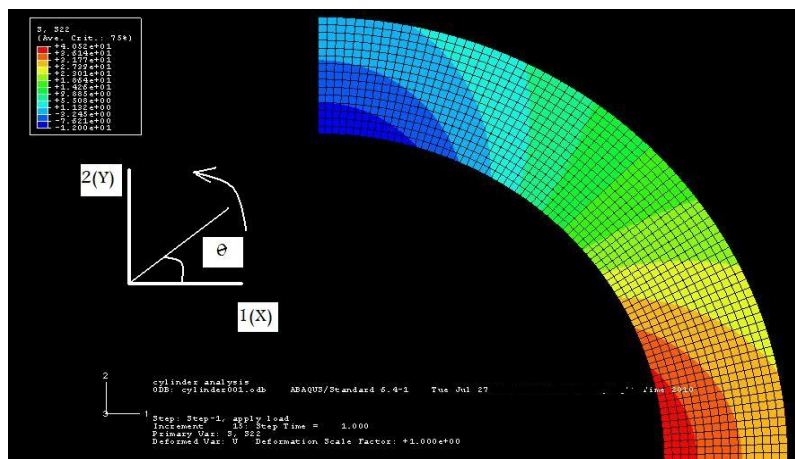
Fig. 2 The mesh and stress for one quarter of the cylinder

3. FE Implementation of External Holes

The effect of external hole, which considered as stress raiser, also discussed. Figure 3 shows a quarter of the cylinder with the established hole. The mesh and generated stresses results for hole diameters of 1 mm and hole depth of 0.5 - 4.5 mm are shown in Fig. 4 - 12. It is clear that, the maximum hoop stress generated at the root of the hole and its value varies with the hole depth. The hoop stress at the depth of 0.5 mm is found to be σ_t = 85.6586 MPa and that at hole depth of 4.5 mm is σ_t = 293.148 MPa for internal operating pressure of 12 MPa. Therefore, the hoop stress increases with the increase of the hole depth. . Also it is cleared that, the internal holes affects the cylinder more significantly than external holes.

The variation of the maximum hoop stress versus the internal pressure for the external holes with diameter 1, 1.5, 2 and 2.5 mm shown in Fig. 13 – 16. It noticed that, the internal holes affect the hoop stress more significantly than the external holes due to

the influence of the internal pressure. A hole with diameter 1 mm and depth of 4 mm teds to safety operating condition at pressure of 14 MPa. Also, the same safety working conditions can be obtained for hole diameter of 1.5, 2 and 2.5 mm at depth of 4, 4.5 and 4 mm receptively.
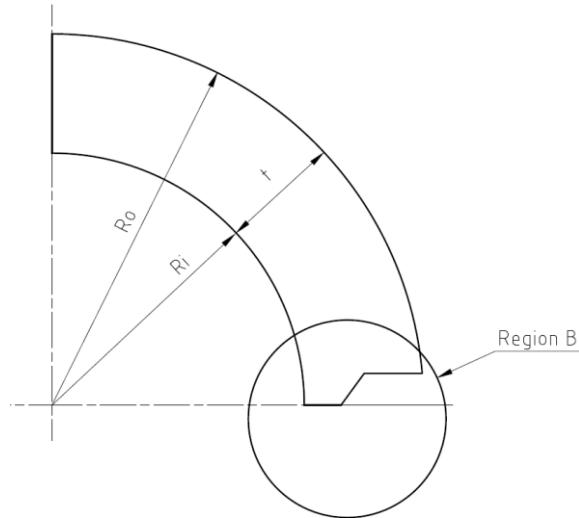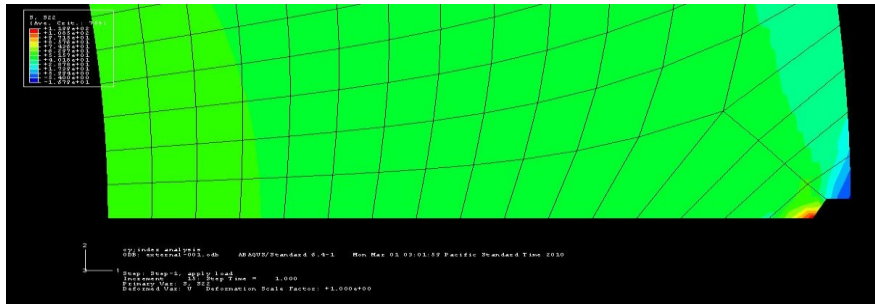

Fig. 3 Cylindrical external stress raiser

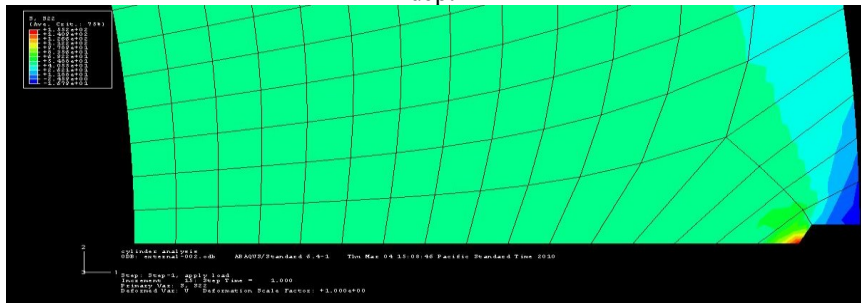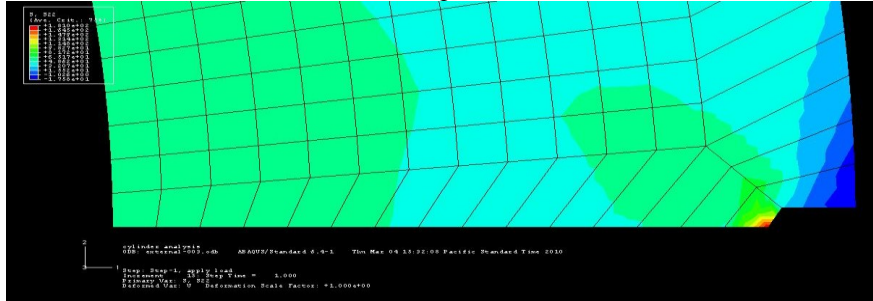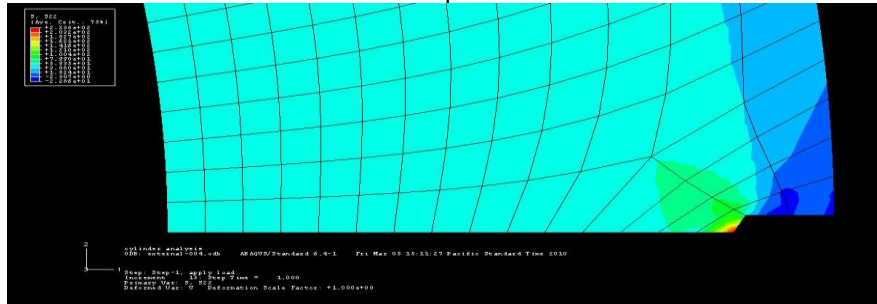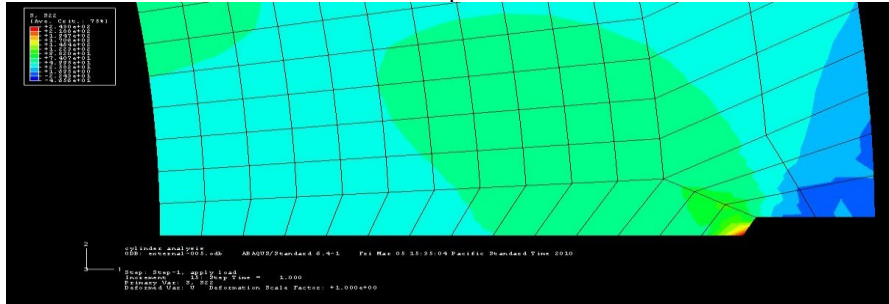Fig. 4 Hoop stress generated due to external hole of 1 mm diameter and 0.5 mm hole depth

Fig. 5 Hoop stress generated due to external hole of 1 mm diameter and 1 mm hole depth

Fig. 6 Hoop stress generated due to external hole of 1 mm diameter and 1.5 mm hole depth

Fig. 7 Hoop stress generated due to external hole of 1 mm diameter and 2 mm hole depth

Fig. 8 Hoop stress generated due to external hole of 1 mm diameter and 2.5 mm hole depth
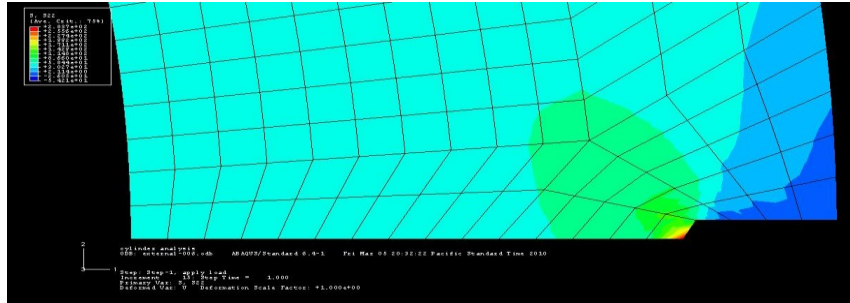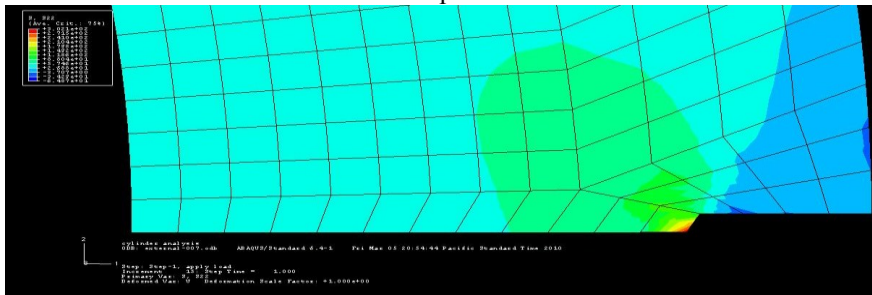
Fig. 9 Hoop stress generated due to external hole of 1 mm diameter and 3 mm hole depth

Fig. 10 Hoop stress generated due to external hole of 1 mm diameter and 3.5 mm hole depth
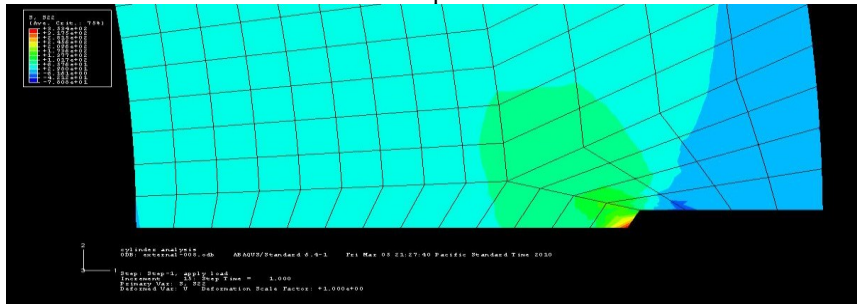

Fig. 11 Hoop stress generated due to external hole of 1 mm diameter and 4 mm hole depth
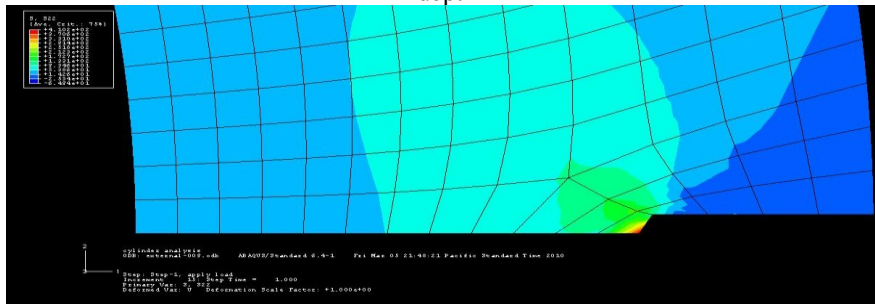
Fig. 12 Hoop stress generated due to external hole of 1 mm diameter and 4.5 mm hole depth
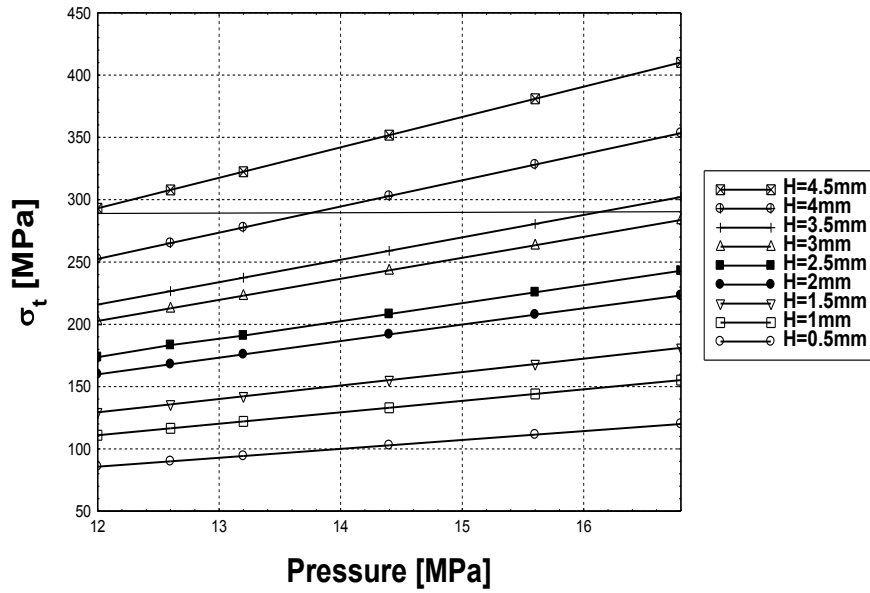

Fig. 13 Variation of tangential stress versus acting pressure for external cylindrical raiser (external hole) with 1 mm of different hole depth
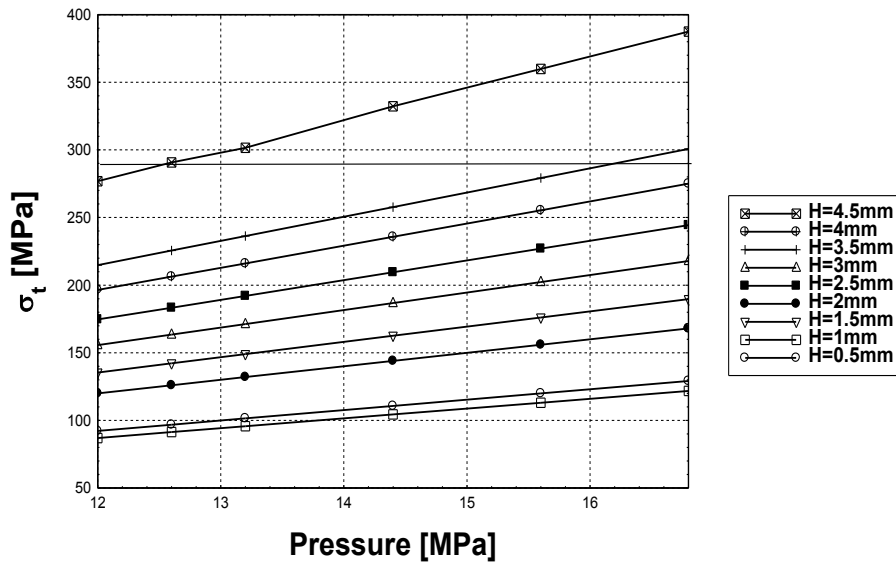
Fig. 14 Variation of tangential stress versus acting pressure for external cylindrical raiser (external hole) with 1.5 mm of different hole depth
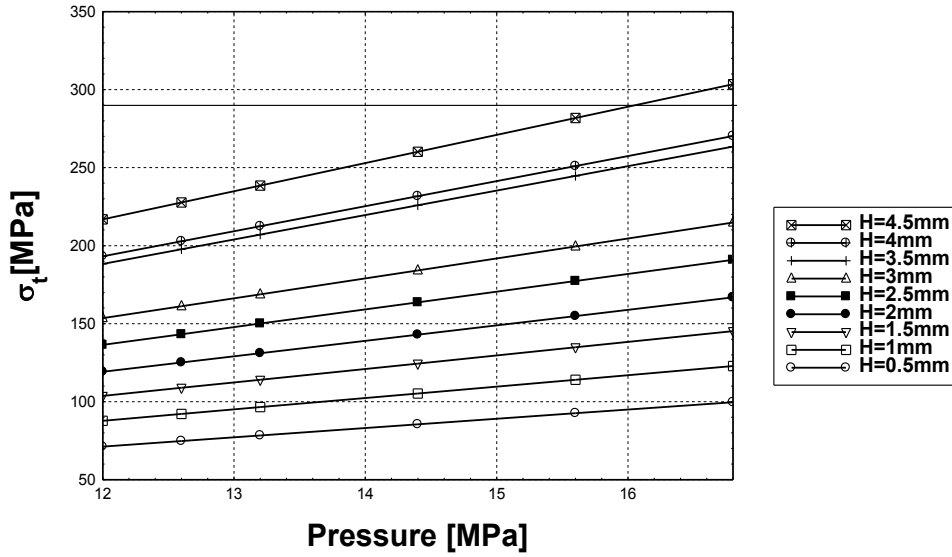

Fig. 15 Variation of tangential stress versus acting pressure for external cylindrical raiser (external hole) with 2 mm of different hole depth
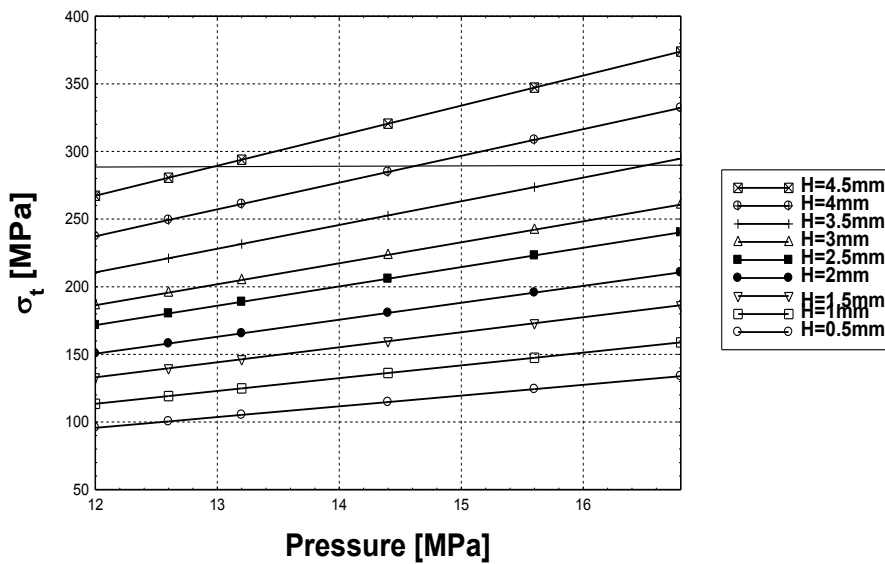

Fig. 16 Variation of tangential stress versus acting pressure for external cylindrical raiser (external hole) with 2.5 mm of different hole depth

4. Conclusions

According to the theoretical results, which obtained from the theoretical treatment of hydraulic cylinders, the following conclusions were drawn:

1. Presence of holes on the cylinder surfaces tends to increase the hoop stress. Furthermore, the hoop stress increase with increase of the hole diameter and depth.
2. The characterizations of holes affect significantly the maximum stress limit.
3. The concentration of stresses occurred at the hole root due to the sharp edge of the notch end.
4. The presence of the stress concentrations at the hole affects, as expected, the stress distributions not only locally but also all over the section.

5. References

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