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Research Article

A Novel Evaluate the Ultimate Strength of Plate Having Cutout Under In-Plane Compression

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Abstract

In this study, investigating the effect of different sizes, cut out shapes and different shapes of the structural to the ultimate strength of steel panels. The nonlinear finite element method is applied in this study. A series of simulations have been performed for the unstiffened panels have the cutouts with different shapes and sizes. Effect of size and cutout shapes to the ultimate strength of steel plates and different shapes of the structural. The relationship between stress and strain is investigated and analyzed. A relationship showed that the effects of different shapes of structural to ultimate strength is presented. The aim of this study is to evaluate the stress and ultimate strength of perforated structures with holes under the compression edge load. Which is the main action type arising from cargo weight and water pressure affecting the ships structure and offshore structures. The cutout is circular and elongated circular in the located in the center of the plate. A series of Abaqus nonlinear finite element analyses performed with cutout size is investigated. By regression analysis of the FEA results is obtained, it helps marine designers to give the optimum structure for simultaneous durability to ensure the maximum saving of raw materials.

Keywords

Ultimate Strength, Finite Element, Plates with Cutout, Ship's Structure

1. Introduction

Flat plates and stiffened panels both intact or with cutouts are all the main structural components of the ships structure and offshore structures. These kinds of structural components subjected to several types of loads. For intact flat panels and the plates with cutouts, many studies have been carried out to evaluation the ultimate strength such as the study performed by Soares C. G. et al. [1].

With the panels have cutouts in the deformation stress distribution in the panels becomes more complex [2]. These holes reduce the bearing capacity of the structure especially for the plates [3]. The cutouts in the flat plate caused imperfections and a great decrease for the load on the structure. Many studies have been carried out on sheet-shaped plates in order to optimize the performance of the panel's anti-warping capability. Various research methods such as theoretical studies, numerical simulation studies, and experimental studies have been proposed [4].

The existence of cutouts in construction structures is nec-

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essary for inspection, pipelines passing through or to be an effective solution to reduce structural weight. The shapes, size and position of the cutouts depending on the purpose of the use or the applied loads. The ultimate strength of the plates with cutouts have been perforated by Wang et al. and Paik et al. [5, 6] using numerical approach. From the results obtained, the effect of the cutouts to the stress and strains was obtained. The ultimate strength of the plate with circle cutouts is better than the plates with square cutouts.

Figure 1. *Cutouts in the ship structure.*

Over the past decades, several studies have been performed to evaluate the ultimate strength of ship structures and offshore architecture. Several methods computing have been developed such as nonlinear finite element methods [7, 8]. However, a large number of empirical studies were conducted to assess the ultimate strength of box beams [9, 10]. Hussein and Guedes [11] Soares has evaluated the ultimate strength of double hull tankers and has also developed the corresponding reliability formulation. Shu and Moan [12] have studied the ultimate strength of the Capesize bulk carriers by using nonlinear FE analysis with the Abaqus software. Cui and Wang [13] have studied the ultimate strength of container vessels under the pure bending, pure torsion and bending - torsional moments combined loading. Cui et al. [14] is presented research results by the numerical on the ultimate strength of cracked plates under compression loads.

For high-strength steel, Saad-Eldeen et al. [15] have experimentally studied the compressibility of high-strength reinforced steel plates with large lightening cutouts. A series of experiments have been performed to evaluate the ultimate strength of the plates with cutouts. Based on the experimental results, it was concluded that for large cutouts structure is used as a solution to reduce weight, the oval-shaped of cutouts is more effective than the circular cutouts with 37% weight reduction while maintaining the bearing capacity.

Therefore ship structure often occurs buckling and collapse under the impact of compression loads if the load exceeds the critical loads. With the increase in vessel size and operation speed of the ship, it significantly affects the limited strength of the vessel. Yang and Wang [16] are studied the buckling of structural panels with elastically restrained edges and subjected to impact loads. Buckling of thin plates and stiffened plate with V-shaped braces under axial impact loads has been studied by Chen and So [17]. Experimental methods and numerical approaches are the most optimum approach is usually to study the ultimate strength of plates under the applied loads.

In the past decades, there have been a lot of studies related to the durability of the panels have cutouts made by scientists [4, 18]. However, in order to accurately assess the effects of the cutouts to the structure, there are still a lot of challenges that have not been satisfactorily resolved. Not only offshore structures but also land-based structures. In contrast to the perfect plates, the ultimate strength of plates with cutouts are always smaller than the ultimate strength of perfect plates [19]. Therefore, it is necessary to directly consider the ultimate strength of plates has cutouts depending on the purpose of the different design of the structure. However, due to the characteristics of the activity plates elements are used for ships and offshore structures are quite different from those on land-based structures. Therefore, the studies for these types of structures are certainly necessary and urgent for current researchers [20].

The purpose of this study is:

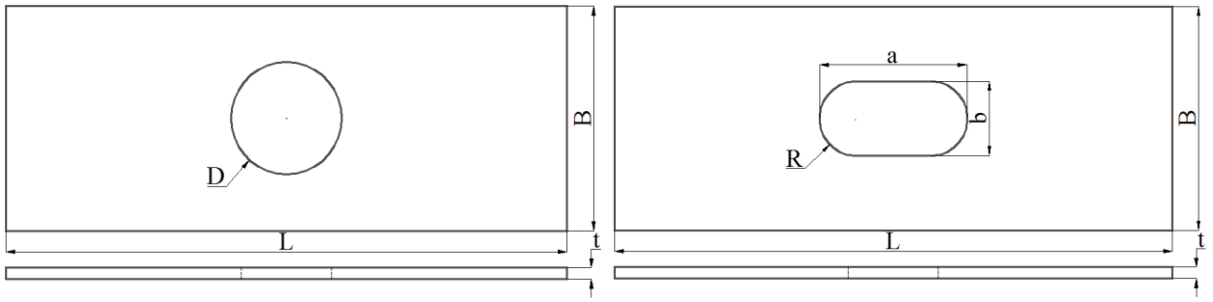
The first: Proposed method of calculating the ultimate strength, not investigating all the cases or the ratio of the cutout diameter compared to the width of the plate.

The second: FE Abaqus$^{@}$Software applications to provide analysis methods, stress and strain study of the plates with cutouts in the center of the plates, used for ships and offshore structures. The finite element analyses (FEA) are carried out to give a detailed assessment of the effect of the cutout size to structural strength.

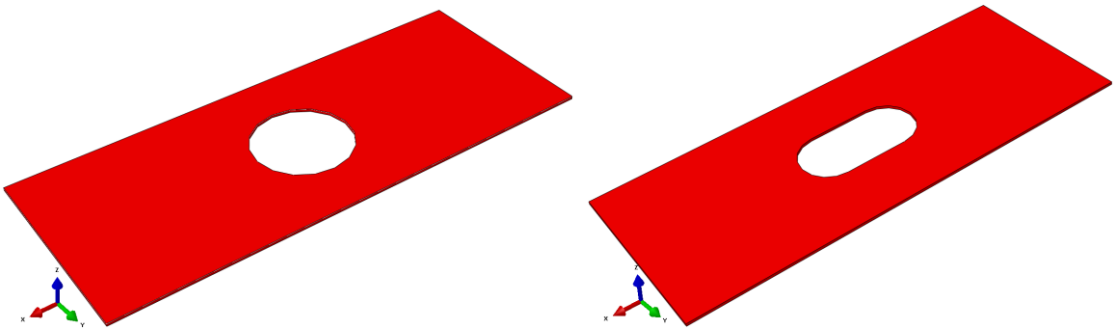
2. Modeling Analysis and Boundary Conditions

For ships and offshore structures, cutouts are usually made in plates of ballast water tanks, tanks, holes reduce weight.

Normally, typically for the plate after being cut out, there will be reinforcement structures around intended to compensate for the structure of the removed cutout. However, at present to analysis exactly the size is reinforcement structure how much, the ship designers are often based on the formula presented in the rules. Thus, increasing the design weight of design structures. In this study, were given the correct comparison of the effect of being cutouts compared to the complete structure with results obtained by FEA analysis.



(a) 2D of circle cutout (b) 2D of Elongated circular cutout



(c) 3D of circle cutout (d) 3D of Elongated circular cutout

Figure 2. *Modeling analysis.*

In the present study consider the ultimate strength of the structure. The geometric shapes of the rigid plate shown in *Figure 2*. As shown in *Figure 2*, the size of the plate is $L \times B \times t$ (L is the length of the plate, B is the width of the plate and t is the thickness of the plate) are surveyed. Young module is $E = 200000 Mpa$, yield stress material is $\sigma = 690\ N/mm^2$ and Poisson's ratio is $\nu = 0{,}3$. Assuming that the plate materials are always in the elastic region. where: x, y and z denote longitudinal, transverse and vertical directions, respectively. The length, total width, and thickness of the plate are denoted as *L, B, t; D* is the diameter of the circle cutout, *R* is the radius of the elongated circular cutouts, *a* is the elongated circular cutouts length, *b* is the width of the elongated circular cutouts.

Table 1. *Geometric properties of the plate with cutouts.*

Plate: *L*=500 *mm*; *B*=200 *mm*; *t*=3 *mm*	**Circle cutout**	**Elongated circular cutout**
Case 1	*D* =60 mm	*a* = 80; *b* = 40; *R*= 18
Case 2	*D*= 100 mm	*a* = 132; *b* = 66; *R*= 32
Case 3	*D*= 140 mm	*a* = 184; *b* = 92; *R*= 43

When calculating the ultimate strength of the plate, it is necessary to establish nonlinear materials models according to the relationship between stress and strain. In this study, the finite element models built into Abaqus is used to consider

the effect of rotation restrictions along the edges. To simplify the modeling and saving computational time, FE modeling without include transverse and longitudinal frames are often used. The boundary conditions are shown in Figure 4.

The plates are weakened by circular cutouts under the load. In these cases, stresses and strain in the area near the cutouts can be estimated by two different approaches. First, the finite element formulations provide exact solutions for a wide range of available options related to modeling problems. The built-in formulas have been integrated into this software have been widely applied to the problem of research ultimate strength structural. However, the finite element method requires exactly meshing problem, especially around the edge of the cutouts, if the meshing in this area is not adequately concerned, it will lead to inaccuracy of the results obtained. But if the mesh is divided into too small will significantly increase the computing times for analysis without much change the results obtained. In the second approach, a series of experimental formulas have been synthesized, which is a faster than computing solution, a more suitable solution to begin the preliminary design problems without requiring high accuracy. Such formulas are so quick methods to conduct an analysis of stresses around the cutouts section. This method is based on functions approximation is used to fast convergence.

Due to modeling the plate of ship structures, the S4R element type each element node has six degrees of freedom are used to model the structure. Numerous studies have demonstrated that initial deflection is a very important influencing factor for ultimate strength analysis of ship structures [21, 22]. Therefore, the initial deflection should be considered adequately during structural analysis. In order to simplify the calculation, in this study we only limited consideration of the impact of the cutouts to the ship structure, initial deflection structure as neglected. The next study we will consider a detailed assessment of the effect of the initial deflection to the ultimate strength of these structures.

A convergence study with finite element meshing was carried out to analysis the FEA of the plate shown in *Figure 3*.

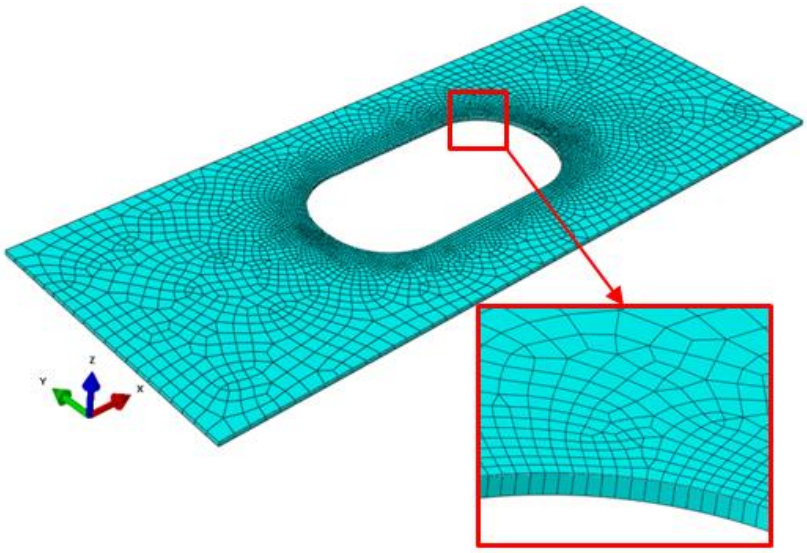


Figure 3. *Finite element meshing.*

3. Loads and Boundary Conditions

Nowadays, most of the practical design criteria design for the buckling and ultimate strength of the ship structure panels is focused on simplified boundary conditions, such as clamped boundary conditions or simply supported [23, 24]. Stiffened plates are supported by transverse frames and longitudinal girders along the edges, limiting rotational restraint stiffness stability.

3.1. The Initial Imperfection

In the process of manufacturing and welding of the ship steel panel, it is inevitable to cause some initial imperfections. These imperfections are mainly welding residual stresses and initial deflection..., all of them lead to a reduction in the ultimate strength of the ship structures [25]. Recently, many studies have shown that the effect of residual welding stresses on the ultimate strength of ship structures is very small [26, 27].

Abaqus can automatically perform the steps of analysis. However, the users need to assign the initial boundary conditions during the basic setup process. At the same time set up the next analysis steps, assign the load in the analysis of the next steps. The boundary conditions are set by finite element analysis Abaqus software. The plate is divided into nodal points and has

constraint with each other. These relationships are through node deformation and displacement respectively. In this study, the plate is fixed on one end of the rigid end, the other end is capable of translational in the X-axis as shown in Figure 4.

3.2. Load Conditions

For plate structures in the ship the most types of load conditions that often cause damage structural are the compressive loads and water pressure on the structure. The computational model is applied in this study is the plate with cutouts subjected under compression loads was selected to study the effect of compressive loads on the ultimate strength structure.

The load acting on offshore structures are often complex loads. But in order to simplify the problem, in this study we separate the load components. The calculated load in this paper is the vertical plate load (the load is parallel to the X-axis).

Abaqus software allows the definition of material properties of the model, the effect of reciprocity between the details element, loads, boundary conditions... directly on the geometric model. It is not mandatory to define the element directly on the element and the node points when redistributing the mesh structure. These parameters are not needed to be redefined.

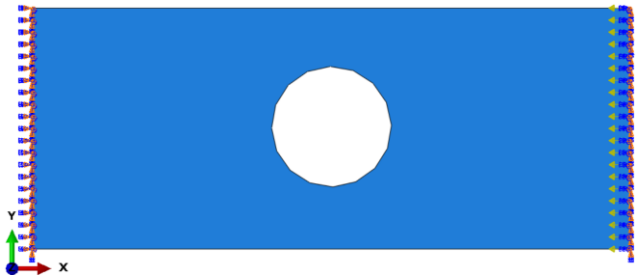
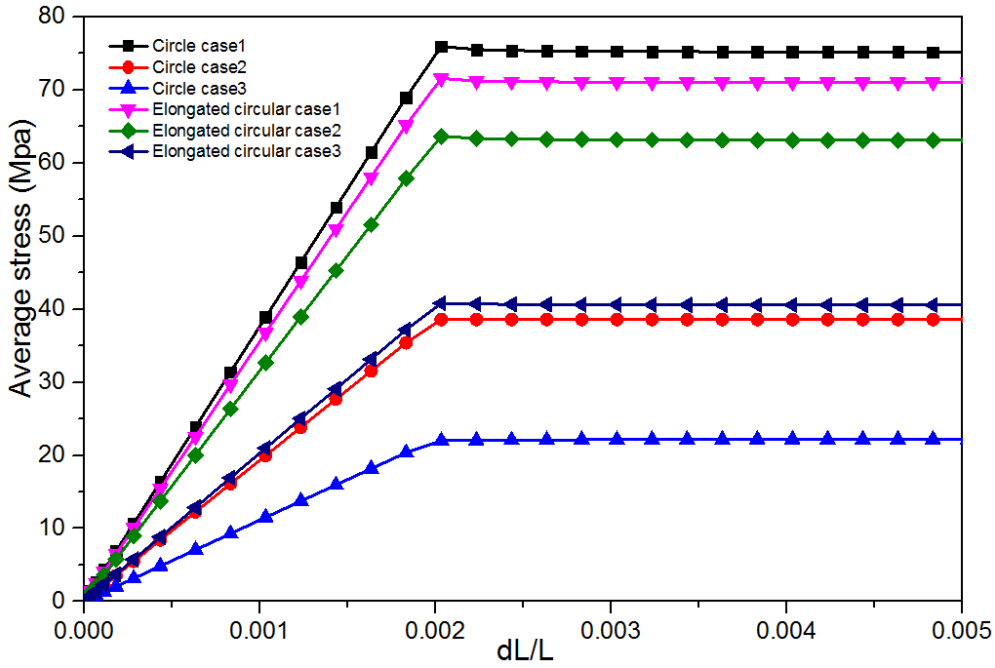


Figure 4. *Loads and boundary conditions.*

4. Results and Discussion

Figure 5 shows the stress and strain relationship for the plate with cutouts. From the graph, it shows clearly that in *Figure 5* the circular cutouts make the ultimate strength lower than the elongated circular cutouts except for case 1. From the results obtained, it is necessary to see with small holes that consider cutting out circular shapes. These comments help the ship designers to make reasonable choices in the process of designing ships and offshore structures.

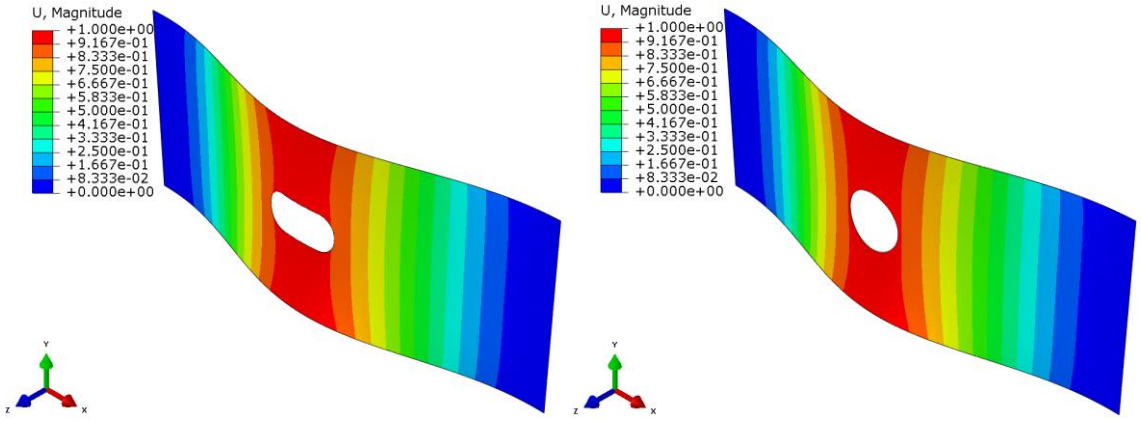


where: dL is deformed according to X-direction; L is the length of the plate; dL/L is the ratio of deformation divided by length.

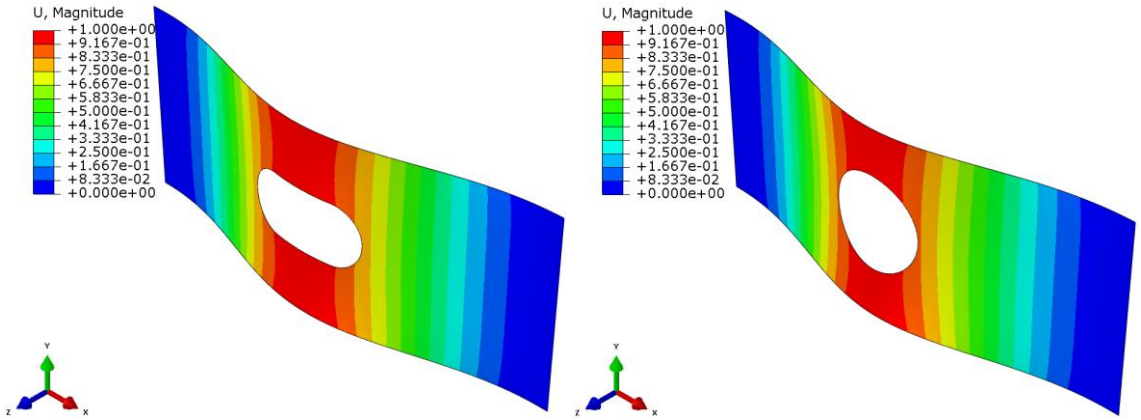
Figure 5. *Relationship between stress and ultimate strength when changing the circle cutout size.*

The results of the first buckling load of the plate are given in Figure 6. The stress and strain distribution of the plate with the cases of the survey are shown in Figure 7. From the obtained results, it was shown that the plate with cutouts, the strength reduction phenomenon will directly affect around the edge of the cutouts area. This suggests that when structure with cutouts needs has adequate reinforcement around the edge of the cutouts to insure ultimate strength. At the same time reduce the stress concentrated in this area. From the results obtained, compared with other similar works [15, 28], we found that the results obtained are completely reasonable and provide a valuable scientific reference value for

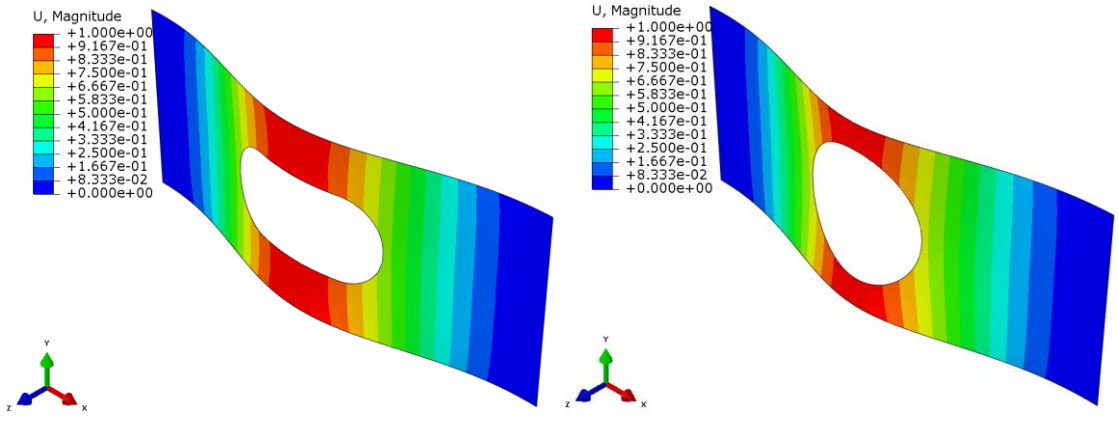
scientists and researchers of the ultimate buckling ship structure.



(a) Elongated circular cutouts case 1 (d) Circular cutouts case 1

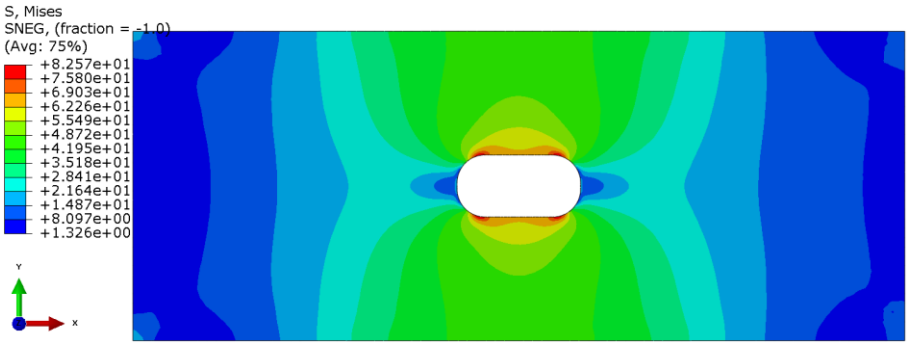


(b) Elongated circular cutouts case 2 (e) Circular cutouts case 2

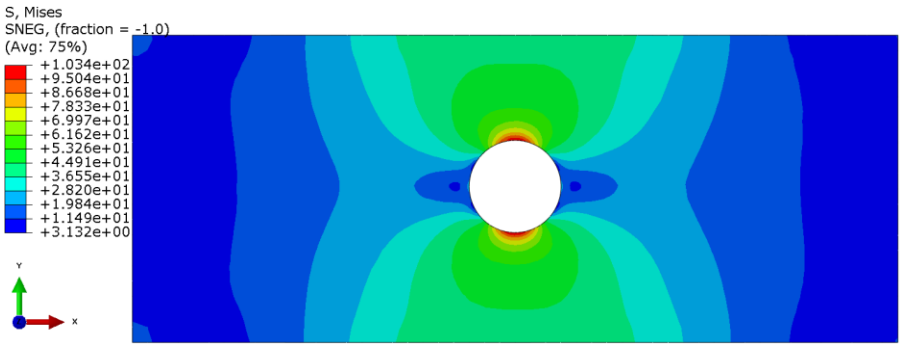


(c) Elongated circular cutouts case 3 (f) Circular cutouts case 3

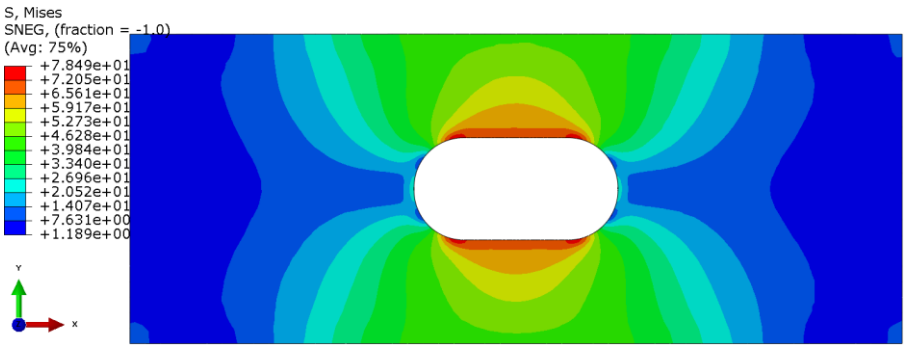
Figure 6. *First buckling mode analysis result of case 1, case 2 and case 3.*



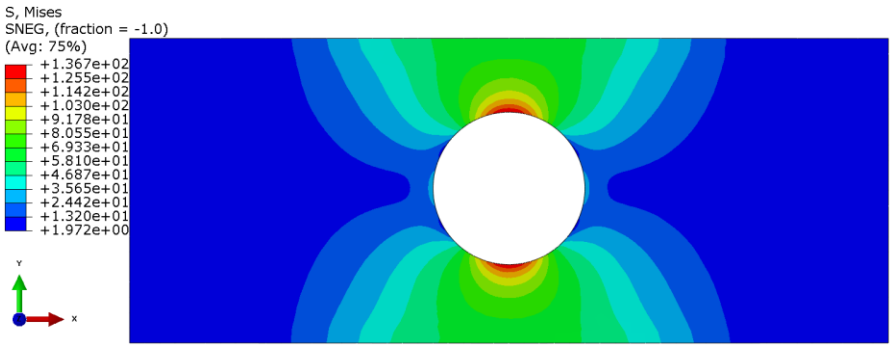
(a) Elongated circular cutouts case 1



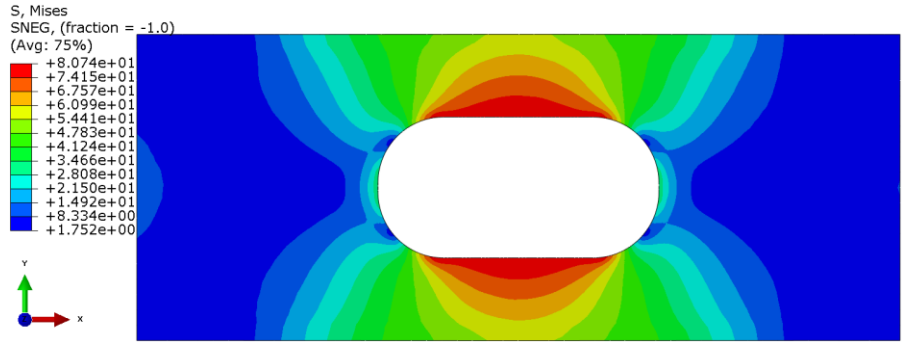
(d) Circular cutouts case 1



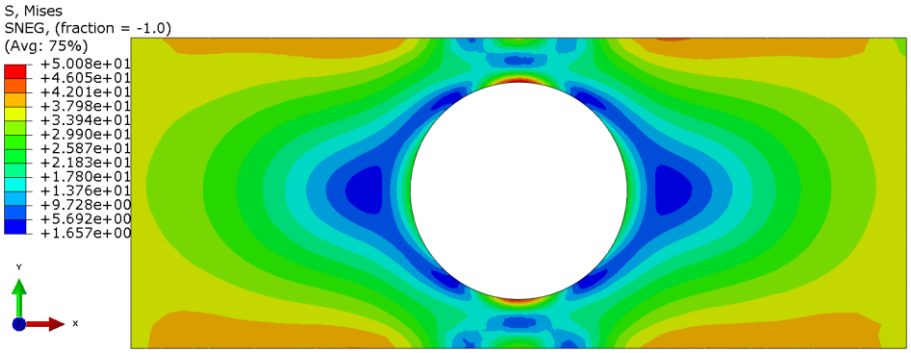
(b) Elongated circular cutouts case 2



(e) Circular cutouts case 2



(c) Elongated circular cutouts case 3



(f) Circular cutouts case 3

Figure 7. *Stress and strain of plate.*

5. Conclusion

This presents a study, the effect of the cutouts on a flat-panels. The nonlinear finite element analysis method has been developed to assess the effect of the cutouts on ship structure and offshore structure architecture under compression load. Finite element analysis software can be used to experimentally investigate for studying the effect of the shape of the cutouts to the ultimate stress of structural plates. The cutouts clearly affect the stress distribution in the plate leading to affect the ability to load. This reduction depends on the size of the cutouts.

1) A series of numerical simulations have been performed for cutouts with different shapes and sizes. The effect of size and shape of cutouts, the structural configuration, stress, strain, ultimate strength have been investigated and analyzed.
2) The nonlinear FE methods are used to calculate the ultimate strength of plate in the ship structures and offshore structures under compressive loads in the plane. The influence of boundary conditions on ultimate strength has been surveyed in detail.
3) With the method are proposed to help researchers in this direction can be calculated and survey entire cases when cutouts size appear on the structure. In the next study, different types of loads, load combinations, with different kind of cutouts or different positions of cutouts will be carried out by us to evaluate the ultimate strength of the commonly applied types of structures are often used for ships as well as offshore structure.
4) The numerical results analysis obtained in this study is useful for evaluating the ultimate strength of ship structure panels and offshore structures with cutouts subjected under to compressive loads in the plane. In the next study in the future, the initial residual stress conditions will be considered more fully.

Conflicts of Interest

The authors declare no conflicts of interest.

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