Stress Concentration Analysis on Ship Plate with Hole using Numerical Approach

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Abstract: The selection of construction firms affects the stress that occurs on the ship. Stress concentration on the construction of the vessel is caused by the load when the ship is operating. A tensile test used to verify the material strength and obtain the maximum stress range that could work on the ship material. In this study, the analysis is conducted to determine the stress concentration of perforated plate stress on the ship. This analysis uses numerical calculation methods and validates with analytical. Based on these results, the approach might use to validate and applied for other shapes.

1 INTRODUCTION

Stress is a factor needed to calculate details when designing ship construction. In its operation, the ship is subject to stress due to a load of ocean waves. Stress work on ship occurs at some point. Stress gradients that have a small area with a dominant red colour called a stress concentration. The stress concentration carries out in the hotspot area. The effect of stress on the hotspot may result in fatigue. Fatigue occurs due to the influence of size, shape, and location rather than damage. Stress distribution around the hole is shown in Figure 1.

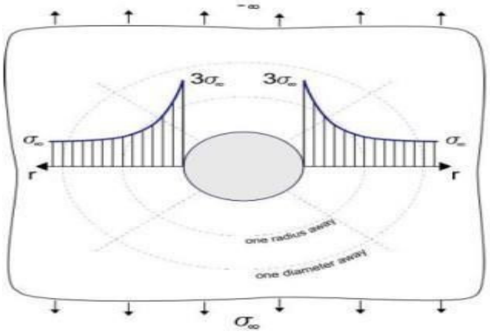

Figure 1: Distribution of stress concentration.

Simple construction of a ship was studied to observe the occurrence of failures with crack applications. This research aims to obtain the difference between the numerical and analytical methods. Thus, these results can be applied as a reference in applying the size, shape, and location of the damage to avoid stress concentration.

2 LITERATURE REVIEW

In general, the stress concentration occurs due to tensile load and other factors that fail ship construction. Damage is assumed to be holes that cause stress concentration concentrations (Belamri, 2009). Stress concentration area could create to reduce the stress concentration of the critical area (Vable, 2010). Cracks were observed during operation to predict construction life. From the observations, the stress concentration increases in proportion to the magnitude of the damage (Ogeman and Mao, 2014). Previous research analyses plates applicated with axial load conditions. Investigations of the load carry out to prevent failure. Axial load failure occurs in the stress concentration area. The development of damage measurement was an early stage to measure the magnitude of the stress. The stress that occurs is measure in a certain period. This study aims to prevent the stress concentration that occurring on the plate with a hole. (Gokul, Kuriakose and Kurian, 2016). Some cases of failure occur in detailed construction so a simple form of construction is required taking into account strength requirements

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(Sujiatanti et al., 2018). Most of the cracked damage to structural fatigue occurs under repeated loads. A Crack has appeared on a plate that has a large stress intensity. Stress concentration calculation is required to evaluate crack on ship construction (Takaki and Gotoh 2020). Based on several variations in this study, an evaluation of the stress concentration was carried out to obtain the stress concentration factor in each variation of the holes on the plate. This hole represents a detailed form of construction on a ship, for example, dry holes, scallops, and manholes. The construction details are an important part that serves to reduce stress.

2.1 Working Load

In this research, the tensile load applies to determine the stress distribution that occurs. This condition is following where the plates on the ship experience tensile and compressive stresses. The load is applied on the model. The load condition is placed at the end of the plate and clamped at the other end.

2.2 Stress Concentration

The stress concentration factor (*K*) is a nondimensional value applied to measure the concentration of stress that occurs in the material. Stress concentration can also be mentioned as a stress riser. The maximum nominal stress occurs on section a-a, which is taken through the bar's smallest cross-sectional area shown in Figure 2.

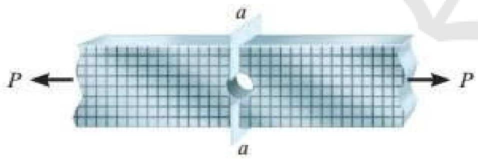

Figure 2: Tensile force working principle.

Analytically, stress concentration calculation on the perforated plate has been approached using several variations and resulted in value for the stress concentration factor on the perforated plate. The stress concentration factor is influence by the ratio of the plate width and the hole diameter. Where the large hole gives different behaviour to the *K* value is all created the table scheme shown in Figure 3.

Influence value of *K* by the radius and width where the closer the ratio value to 0, the greater the stress concentration.

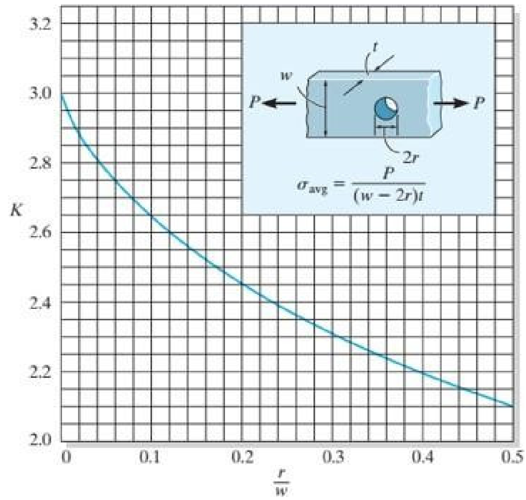

Figure 3: Ratio of stress concentration.

3 METHODOLOGY

The method in this research is numerical and validated with analytical solutions. The numerical method is developing to obtain the interaction of the load conditions, shape, and size of the hole so that the stress concentration factor. Furthermore, compare the results of the stress concentration factor to know the difference in error between the two methods is seen. The model analysed is a plate with a length of 300 mm and a width of 50 mm. The variation of the holes in the centre of the plate is determined according to the reference ratio (Hibbeler 2011). Some of the variations are shown in Table 1.

Table 1: Variations of radius.

No	w(mm)	r(mm)	r/w
1	50	0	0
2	50	5	0.1
3	50	10	0.2
4	50	15	0.3
5	50	20	0.4
6	50	25	0.5

Based on these variations, the stress concentration is calculated using the equation below. The stress concentration factor is determined as the ratio of the maximum stress (σ_{max}) is divided by nominal stress (σ_{nom}), which can obtain follows Equation (1).

$$K = \frac{\sigma_{max}}{\sigma_{nom}} \quad (1)$$

The nominal stress is made from the total load by neglecting the concentration areas such as the hole. The approximate stress in the centre of the plate width is solved by equation (1). The nominal stress value is obtaining from the force (F) divided by the cross-sectional area (A) as in Equation (2):

$$\sigma_{\text{nom}} = \frac{F}{A} \quad (2)$$

Area (A) obtained from the cross-sectional width of the plate. Then the value of K can be determined by Equation (3) by (Young and Budynas, 2002).

$$K_t = 3.00 - 3.13\left(\frac{2r}{D}\right) + 3.66\left(\frac{2r}{D}\right)^2 - 1.53\left(\frac{2r}{D}\right)^3 \quad (3)$$

The approach used the above equation to get the stress concentration. Where the stress concentration depending on the ratio of the width and diameter of the hole. The results of the large stress concentration factor on the plates were then analysed by numerical methods. The development of the numerical method is carried out in several stages. Numerical modelling is develops using the finite element method (Misbah, et al. 2018). In the analysis, obtaining a good accuracy required the convergence of studies by changing the element size to obtain great result. The relationship between the number of elements and the accuracy of the results presented in Figure 4

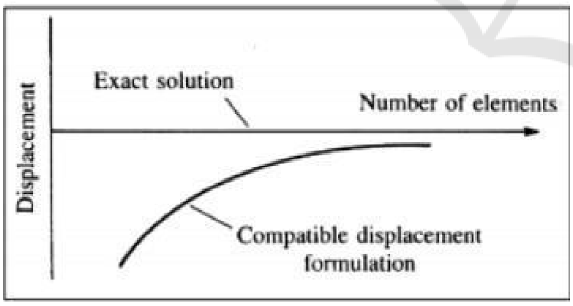

Figure 4: Convergency study.

The results will begin to stabilize and not be affected by the change of elements in range size and amount of element (Logan, 2011). The initial stage is modelling each variation of the model to determine the amount of stress that occurs. This modelling aim is to simplify the experimental process. Then, the numerical results are validated by analytic calculations. A model made of steel with material properties such as properties used as density (ρ), Young's modulus (E), and Poisson's ratio presented

Table 2: Material properties of steel.

Materials	ρ (kg/m3)	E (MPa)	υ
Steel	7850	2.06×10^5	0.3

in Table 2. Model is defined in Figure 5 (a) left and is the boundary condition (b) right.

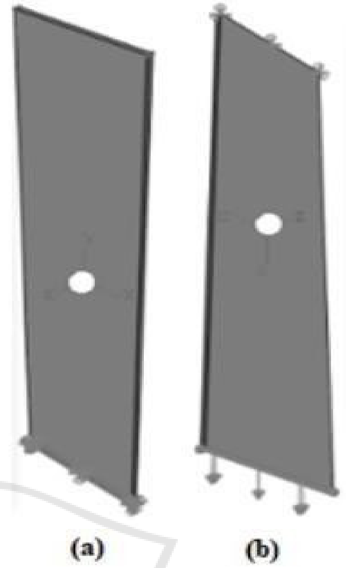

Figure 5: (a) Model and (b) Boundary condition.

Furthermore, meshing was carried out to obtain convergent results and continued in the analysis of the results.

4 RESULTS AND DISCUSSION

The calculation design of variation hole radius and the length ratio determine using equation (3) to obtain the stress concentration factor (SCF). Theoretically, the stress concentration factor is proof. That is a show from the big will decrease the value of the stress concentration. The results of the analysis of analytical calculations are presented in Table 3.

Table 3: Stress concentration factor (K1) analytical.

r(mm)	r/w	K_1
0	0	3
5	0.1	2.595
10	0.2	2.375
15	0.3	2.25
20	0.4	2.15
25	0.5	2.08

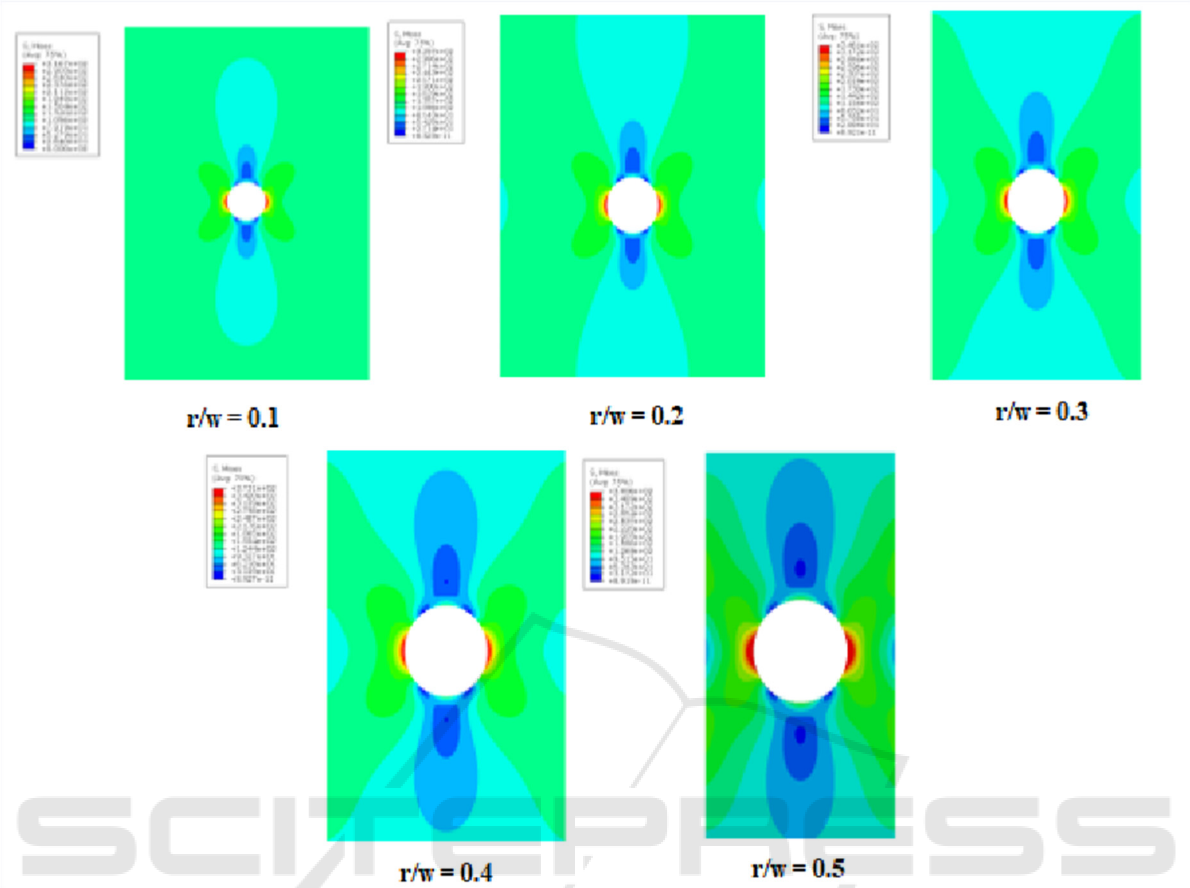

Figure 6: Stress concentration in numerical simulation.

Based on this result, a numerical simulation is performing to ensure that these results be good. Obtained stress contours from the simulation results are then processed to obtain the stress concentration factor. The results of the simulated stress distribution are shown in Figure 6. The stress concentration is centre on the left and right sides of the hole due to the working tensile load. The resulting contours in numerical analysis are the same as in Figure 7.

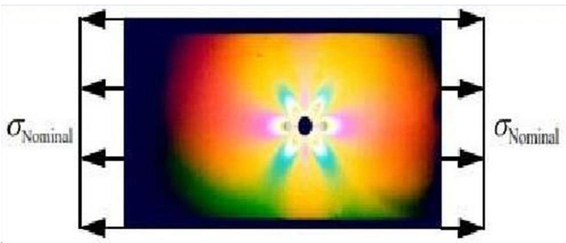

Figure 7: Contour of the stress concentration (Vable, 2010).

Values of stress in Table 4 are using to input in the equation for calculations. That calculation produces the value of the stress concentration factor using Equation (1).

Table 4: Maximum stress value.

Type	Max Stress (MPa)
1st Variation	316
2nd Variation	326
3rd Variation	346
4th Variation	373
5th Variation	380

The stress distribution on the side of the plate is shown in Figure 8. The resulting stress distribution

Table 5: Stress concentration factor (K1) numeric.

r(mm)	r/w	K_2
0	0	3
8.4	0.16	2.57
10.3	0.205	2.49
13.9	0.278	2.38
17.5	0.35	2.28
25	0.5	2.16

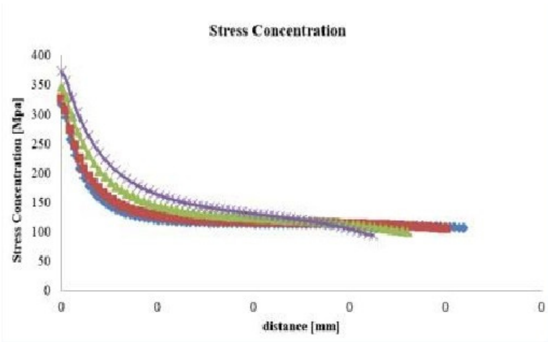

Figure 8: Stress distribution along path.

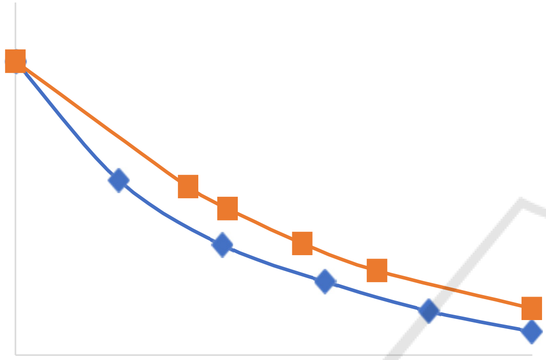

Figure 9: SCF Analytical vs Numerical.

is numerically high in the vicinity of the hole and decreases toward the edge of the plate. That same with Figure 1 above. Finally, from the resulting stress, SCF calculations are carried out so that the values presented in Table 5 are obtained. That comparison of results from the analytical and numerical formula references is present in Figure 9. If attention to the results of the numerical approach, the graph tends to be the same. So that result can be said to be valid with a difference of error below 2%.

5 CONCLUSIONS

Based on the analysis of the analytical and numerical methods approach with the finite element method. This technique allows it to use in other structural forms with the addition of various load conditions. The SCF value resulted in an error below 2% for all variations. In the future, additional experiments need to make sure the results correct.

REFERENCES

Belamri, S., Tamine, T., Nemdili, A. 2009. "Experimental and Numerical Determenation of Stress Intensity Factors of Crack in Plate with a Multiple Holes." Damaged and Fracture Mechanics: Failure Analysis of Engineering Materials and Structures 285 – 295.

Gokul, P.V., Bennet Kuriakose, and Salini Theres N Kurian. 2016. "Numerical Analysis of Thin Plates with Holes." Applied Mechanics and Materials 154-158

Hibbeler, R. 2011. Mechanics of Materials Eight Edition. United Stated: Pearson Prentice Hall.

Logan, Daryl L. 2011. A First Course in the Finite Element Method. 5th. Kanada: Cengage Learning.

Misbah, Muhammad Nurul, Septia Hardy Sujiatanti, Dony Setyawan, Rizky Chandra Ariesta, and Satriyo Rahmadianto. 2018. "Structural Analysis on the Block Lifting in Shipbuilding Construction Process." MATEC Web of Conference. Surabaya: EDP Sciences. 1 - 6.

Ogeman, Viktor, and Wengang Mao. 2014. "Uncertainty in Stress Concentration Factor Computation for Ship Fatigue Design." Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE). San Fransisco, USA: ASME.

Sujiatanti, Septia Hardy, Totok Yulianto, Wing Prasetyo Akbar Putra, and Rizky Chandra Ariesta. 2018. "Influence of the Cut-out Shape on the Fatigue Ship Structural Detail." 6th International h International Seminar on Ocean and Coastal Engineering, Environmental and Natural Disaster Management. Surabaya: SCITEPRESS. 111 -115.

Takaki, Yoshifumi, and Koji Gotoh. 2020. "Approximate weight functions of stressintensity factor for a wide range shapes of surface and an embedded elliptical crack." Marine Structures 70: 1 -22.

Vable, Madhukar. 2010. Mechanics of Materials second Edition. Michigan: Michigan Technological University

Young, W.C., and R. G. Budynas. 2002. Roark's Formula for Stress and Strain 7th Edition. United States: McGraw -Hill.