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NUMERICAL INVESTIGATION OF THE BUCKLING STRENGTH BEHAVIOR OF RING STIFFENED SUBMARINE PRESSURE HULL

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ABSTRACT

A growing trend in the design of the submarine proves the need for increasing the level of water depth, especially for the military activities. Moreover, the complexity of modern submarines and their demand for efficiency, safety, and greater reliability, is a challenge for designers in making the design of submarine particular component known as pressure hull. The pressure hull is the main load-bearing structure in a naval submarine. The basic structural component is a ring-stiffened cylindrical metallic shell under an external hydrostatic pressure load. The ring-stiffeners forestall buckling of the shell until the material exhibits yielding, thereby taking advantage of the full material strength and increasing the structural efficiency. The aim of the paper is to investigate the buckling strength behavior of ring stiffened submarine pressure hull. The influence of the bulkhead positions on the buckling strength behavior of the ring stiffened submarine pressure hull are presented and discussed.

Key words: Ring Stiffened Structure, Buckling Strength Behavior, and Submarine Pressure Hull.

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1. INTRODUCTION

Indonesia's territorial sea is one of the most important checkpoints in the submarine world. Most of the global trade should pass through the Straits of Malacca and the shallow waters around the coast of the Indonesian archipelago. This situation makes Indonesia needs submarines that can operate at sea for up to three weeks. However Indonesia has only two old submarines Chakra, as well as some of the Frigate and Corvette to maintain a wide area. The presence of the modern submarine is absolutely necessary to strengthen the protection of the sea territory of Indonesia, especially at points that are considered vulnerable. A growing trend in the design of the submarine proves the need for increasing the level of water depth, especially for the military activities. Moreover, the complexity of modern submarines and their demand for efficiency, safety, and greater reliability, is a challenge for designers in making the design of submarine particular component known as pressure hull. Commonly, the structure of the submarine consists of two hull components, namely the outer hull which is more focused on the influence of the hydrodynamic loads so-called hydrodynamics hull, and the inner hull which is used to withstand hydrostatic pressure when the vessel in diving conditions. Based on the functions that the inner hull is used to withstand the pressure, thus it is identified as a pressure hull. Pressure hull is usually constructed using a combination of cylindrical shapes, conical and forms a dome. The design is intended to withstand the pressure created as a result of diving at a high level water depth. The increased pressure for any additions to depths of 100 feet which made the increased of hydrostatic pressure about 44.5 psi for sea water and 43.5 psi for freshwater, [1]. Weight submarine is depending on maximum diving depth: the deeper diving depth needs the bigger weight of submarine pressure hull. The level of diving depth that is used as a design consideration is categorized as: the operational diving depth / normal, the maximum allowable level of diving depth (maximum permitted depth) and the level of structural failure (collapse depth). The maximum allowable level of depth is the maximum depth level where the submarine is still safe to operate. The diving depth is only achieved on certain conditions. Collapse depth is the depth where the pressure hull structure has been failed. Instead of hydrostatics, submarines pressure hull should be able to withstand the harshness of shock explosion. Generally, collapse depth is a multiply factor between the safety factor and the operational diving depth (operating depth). In previous studies it has revealed that the value of the safety factor for submarines is ranged 1.5- 2.0, [1]. The safety standard is accepted in the practice of engineering. In a military submarine design, consideration of hydrostatic load at the level of the operational depth and the impact of the blast shock should be given. In conditions of war, the effects of the explosion shock can cause the structure to undergo large deformations, which can lead to material failure. The large size and distance of the explosion blast affecting the effects of underwater explosion shock. The explosion might produce a shock wave for 1 millisecond. The high intensity of the waves might cause damage to the pressure hull submarines and submarine equipment, [2]. Some research on the pressure hull has been done by several researchers, particularly regarding the analysis and design of submarine pressure hull. In 1991, Gorman and Louie [3] developed an optimization method to examine the material, shape and architecture of the pressure hull by considering the strength of the hull (hull yielding), buckling between frame, general instability and instability modes of failure at the local frame. In 1992, Jackson [4] presented the design concept of the submarine on which to base the planning process submarines. Ross has been reviewing the pressure hull conventional and novel design [5-8]. Based on the finite element method and experiment, Ross proposed the improvement of efficiency dome structure with a dome to change the pressure hull submarine [7, 8]. In 1987, Ross introduced a design of axisymmetric pressure hull with swedge stiffened to withstand hydrostatic pressure. Comparison between swedge stiffened with stiffened ring has also been carried out which terms swedge stiffened structure is more efficient than the conventional stiffened ring [9, 10]. In 1995, Ross presented the results of experiments to show the failure of thin walled plastic ring stiffened at cone shell, with uniform external pressure loads, [9]. Yuan also has presented a theoretical analysis of the elastic instability of the cylinder swedge stiffened against hydrostatic pressure loads, taking into account the influence of variation in the angle of the cone cross section, [10]. Liang also did elastoplastic analysis and non-linear response of the swedge model Ross, [11]. In this paper, the study focused on the investigation of the buckling strength behavior of ring stiffened submarine pressure hull. The position of transverse bulkhead and the dimension of stiffener are determined as the influence parameters of the buckling strength performance of the ring stiffened submarine pressure hull. The linear buckling and elasto-plastic buckling is adopted for the numerical analysis.

2. MATERIAL AND METHOD

2.1. The Linear Buckling Analysis Formulations

Thin structures subject to compression loads that haven't achieved the material strength limits can show a failure mode called buckling. Buckling is characterized by a sudden failure of a structural member subjected to high compressive stress, where the actual compressive stress at the point of failure is less than the ultimate compressive stresses that the material is capable of withstanding. In other words, once a critical load is reached, the slender component draws aside instead of taking up additional load. This failure can be analyzed using a technique well known as linear buckling analysis. The goal of this analysis is to determine the buckling load factor, λ, and the critical buckling load. The problem of linear buckling in finite element analysis is solved by first applying a reference level of loading [11-14], F_{ref} to the structure. This is ideally a unit load, F, that is applied. The unit load and respective constraints, Single Point Constraint (SPC), are referenced in the first load steps/subcase. A standard linear static analysis is then carried out to obtain stresses which are needed to form the geometric stiffness matrix KG. The buckling loads are then calculated as part of the second load steps/subcase, by solving an eigenvalue problem:

$$(K - \lambda K_G)\, x = 0$$

K is the stiffness matrix of the structure and λ is the multiplier to the reference load. The solution of the eigenvalue problem generally yields n eigenvalues λ, (buckling load factor) where n is the number of degrees of freedom (in practice, only a subset of eigenvalues is usually calculated). The vector x is the eigenvector corresponding to the eigenvalue. The eigenvalue problem is solved using a matrix method. Not all eigenvalues are required. Only a small number of the lowest eigenvalues are normally calculated for buckling analysis. The lowest eigenvalue is associated with buckling. The critical or buckling load is:

$$F_{crit} = \lambda_{crit} F_{ref}$$

In other words,

$$\lambda_{crit} = F_{crit} / F_{ref}$$

thus

$\lambda_c < 1$ buckling

$\lambda_c > 1$ safe

It should be noted that the displacement results obtained with a buckling analysis depict the buckling mode shape. Any displacement values are meaningless. The same holds true for stress and strain results from a buckling analysis.

2.2. The Simulation Model and Calculations

The full models of ring stiffened pressure hull were used in FEA as shown in Fig. 2. The configuration of the ring stiffened pressure hull was defined as the variation of transverse bulkheads positions. The linear buckling calculations of ring stiffened pressure hull under hydrostatic pressure are performed. In this model, the hydrostatic pressure of the buckling load, which can be obtained by the water depth where the submarine might be operated as the operational condition and the maximum depth which is the structure still not collapse and reliable is introduced.

2.3. The Boundary Conditions and Loading Conditions

General purpose FE software is used for the linear buckling analysis in which the buckling mode shape is taken account. The quadrilateral 4 node element is used. The calculating pressure hulls consist of 4 models which is the variations of transverse bulkhead position is defined. The element number in the model is 4099 beam elements and 35753 shell elements are used to maintain the calculation accuracy. The convergence of calculation by mesh division was confirmed. The cylindrical coordinates were used. The boundary conditions are given at the mid span of the pressure hull at four points as shown in Fig. 1. The rigid body elements (RBE) are inserted at both transverse bulkheads in order to connect the center of bulkhead and the points on outer point of the circle as shown in Fig. 1. The hydrostatics pressure is loaded at the wall of the pressure hull. The rigid body elements (RBE) prevent the oval deformation of both transverse bulkheads, and keep the section in plane under translational and rotational deformation by the hydrostatics pressure. In the commercial software, a rigid link for either small deformation or large deformation can be implemented using RBE.

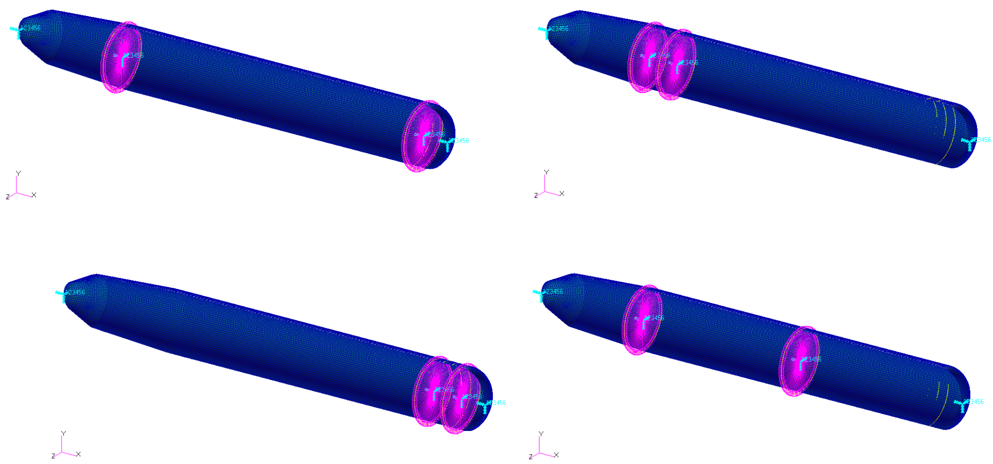
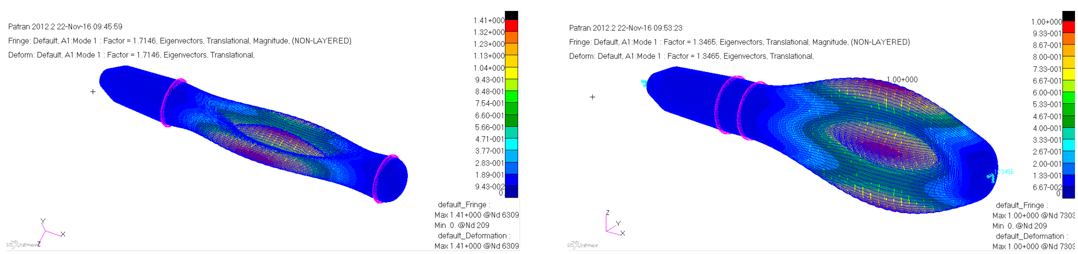


Figure 1 The Boundary Conditions: [a] Model 1; [b] Model 2; [c] Model 3; [d] Model 4.



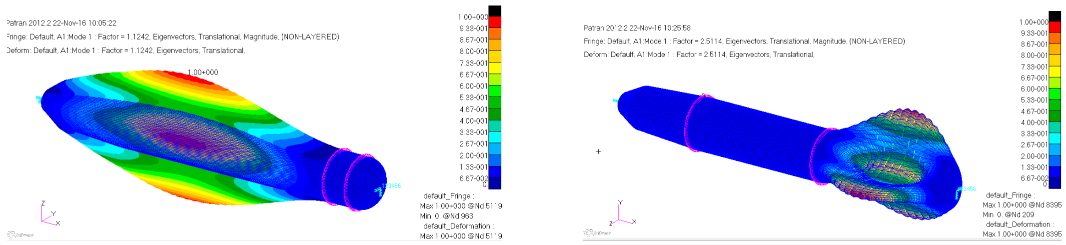


Figure 2 1st mode buckling mode shape: [a] model 1; [b] model 2; [c] model 3; [d] model 4

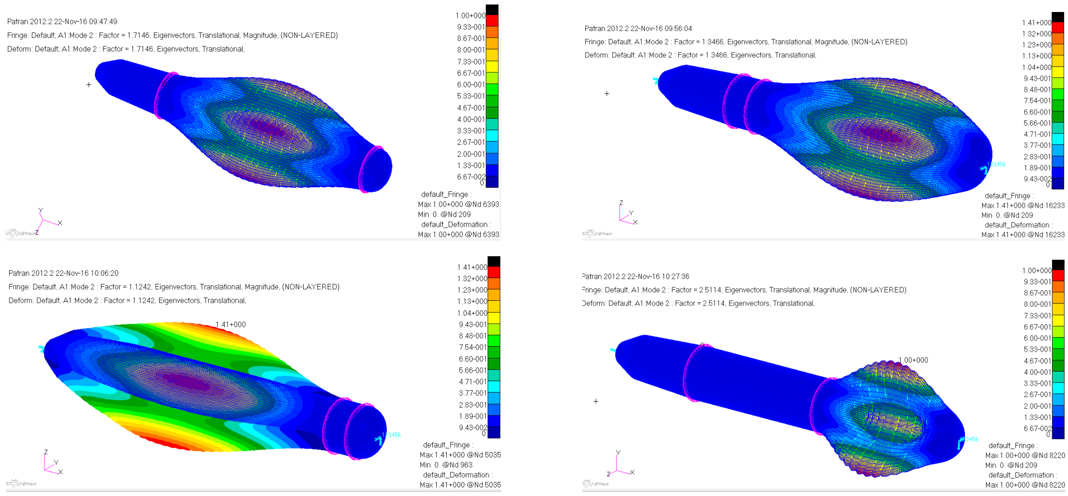


Figure 3 2nd mode buckling mode shape: [a] model 1; [b] model 2; [c] model 3; [d] model 4

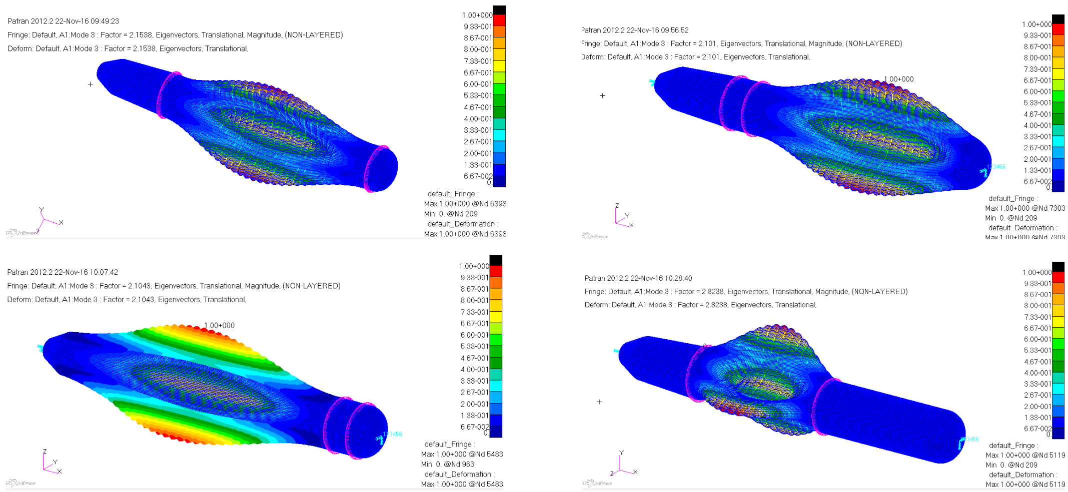
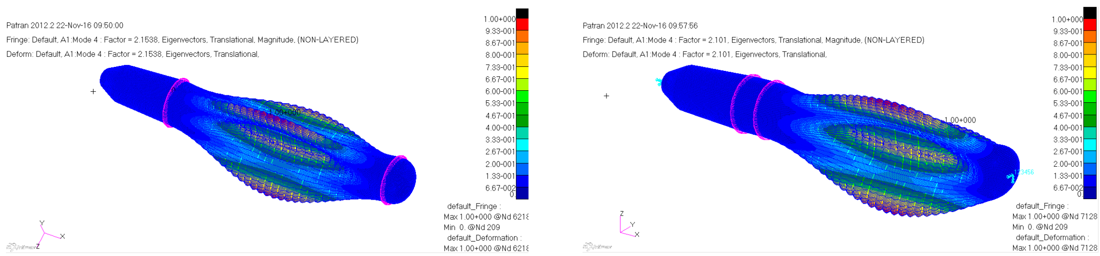


Figure 4 3rd mode buckling mode shape: [a] model 1; [b] model 2; [c] model 3; [d] model 4



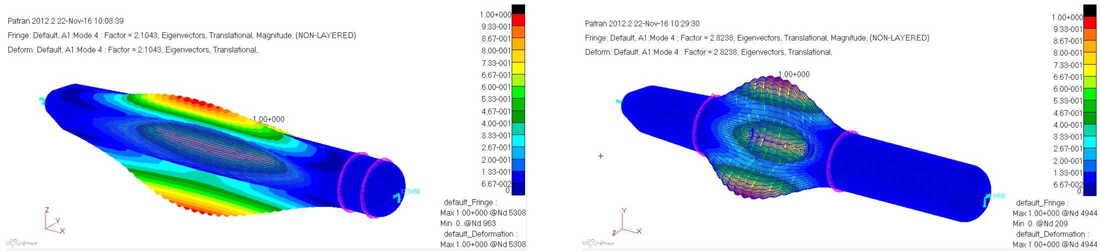


Figure 5 4th mode buckling mode shape: [a] model 1; [b] model 2; [c] model 3; [d] model 4

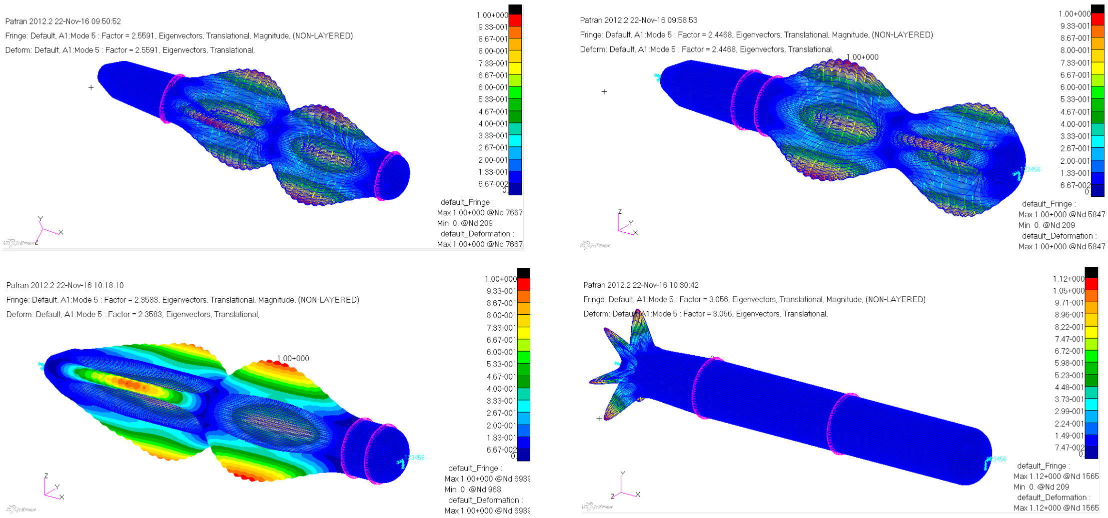


Figure 6 5th mode buckling mode shape: [a] model 1; [b] model 2; [c] model 3; [d] model 4

3. RESULTS AND DISCUSSION

3.1. Linear Buckling Behavior

There are two major categories leading to the sudden failure of a mechanical component: material failure and structural instability, which is often called buckling. For material failures the yield stress is considered for ductile materials and the ultimate stress for brittle materials. Buckling refers to the loss of stability of a component and is usually independent of material strength. The load at which buckling occurs depends on the stiffness of a component, not upon the strength of its materials. When a structure whose order of magnitude of length is larger than either of its other dimensions, is subjected to axial compressive stress, due to its size its axial displacement is going to be very small compared to its lateral deflection is known as Buckling. The linear buckling analysis of the pressure hull models is made by extracting the hydrostatic pressure acting on the shell of the pressure hull and converting it to the compressive pressure. The compressive pressure is the applied on each configuration of the location of the pressure hull transverse bulkheads. The buckling analysis is done and the buckling load factor is obtained. The results of the buckling load factor for each model are shown in Table 1, while the buckling mode shape of the pressure hull buckling might be seen on the Fig 2~Fig 6.

Table 1 Buckling Load Factor of the Ring Stiffened Pressure Hull

Pressure hull design	Mode	Buckling Load Factor	Acceptance Criteria	Status
Model 1	Mode 1	1.7146	1.5000	passed
	Mode 2	1.7146	1.5000	passed
	Mode 3	2.1538	1.5000	passed
	Mode 4	2.1538	1.5000	passed
	Mode 5	2.5591	1.5000	passed
Model 2	Mode 1	1.3465	1.5000	Not passed
	Mode 2	1.3465	1.5000	Not passed
	Mode 3	2.1010	1.5000	passed
	Mode 4	2.1010	1.5000	passed
	Mode 5	2.4468	1.5000	passed
Model 3	Mode 1	1.1242	1.5000	Not passed
	Mode 2	1.1242	1.5000	Not passed
	Mode 3	2.1043	1.5000	passed
	Mode 4	2.1043	1.5000	passed
	Mode 5	2.3583	1.5000	passed
Model 4	Mode 1	2.5114	1.5000	passed
	Mode 2	2.5114	1.5000	passed
	Mode 3	2.8238	1.5000	passed
	Mode 4	2.8238	1.5000	passed
	Mode 5	3.0560	1.5000	passed

Based on the analysis results, it appears that the configuration of the location of transverse bulkhead have influence the buckling strength of the pressure hull. It can be explained that the location of transverse bulkhead have increased the length of unsupported span on the pressure hull construction. The uniformly spacing transverse bulkheads have shown a better buckling strength compared than the non-uniform spacing bulkhead. The uniformly spacing transverse bulkheads was shown in Model 4, therefore the model 4 has the buckling strength pressure hull that able to withstand the load of 2.5114 times the applied load on the pressure hull. However at the model 3, the laying of transverse bulkheads that caused an increased on the length of unsupported span has shown the buckling strength that decreased on 1.1242 times of the applied load. The reduction of buckling strength in 3 models is 123% compared than the model 4. It might also cause the model 3 not meet the acceptance criteria which the buckling load factor of 1.5 is required.

Table 2 The Conversion of Buckling Load Factor to the Submerge Depth

Pressure hull design	Buckling load factor on the 150m submerge depth	Safe submerge depth (1.50/buckling load factor)	Maximum submerge depth (1.0/buckling factor)
Model 1	1.7146	172 m	257 m
Model 2	1.3465	135 m	202 m
Model 3	1.1242	113 m	169 m
Model 4	2.5114	251 m	377 m

Buckling load factor that shows the stability limits of pressure hull structure might be converted into a submerge depth limit for the submarine. The maximum pressure load that is able to be supported by the pressure hull construction is converted using a hydrostatics pressure formula. The result of the conversion of maximum pressure to a maximum submerge depth can be seen in Table 2. Based on this conversion, it appears that model 4 is capable to operate at a submerge depth of 251 m, while the model 3 has a safe submerge depth of 113m and a limit submerge depth of 169m.

4. CONCLUSIONS

The ring stiffened submarine pressure hull was investigated as well as the configuration of influence parameters such as transverse bulkhead position was determined. Based on the results of numerical analysis, it is indicated that all of the configuration of the ring stiffened pressure hull design have excellent buckling strength. The smallest buckling load factor was shown in the scenario 3, with the load factor magnitude 1.12. The largest load factor was shown by the scenario 4 which is the transverse bulkheads was located at the middle part and the engine room bulkhead, with the load factor magnitude 2.511. Accordingly it might be concluded that the transverse bulkhead position have significant influence to the buckling strength of the submarine pressure hull. Although the numerical analyses have shown that buckling strength of the all of configurations of transverse bulkhead position was accepted. However the experiment should be made.

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