A CRITICAL REVIEW ON FATIGUE ASSESSMENT APPROACH IN SHIP STRUCTURAL DETAILS

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ABSTRACT

Review of the methods used in the fatigue analysis of structures has been widely used. The resulting fatigue is primarily the result of repeated loads acting on the structure both internally and externally. Internal loads are caused by the cargo loading and unloading process, while external loads are caused by sea waves. The interaction of the two loads affects the strength of the structure. In this paper, we will discuss materials, residual stresses and environmental factors that cause fatigue in structures. The focus of analysis in this critical review is on the structural details of the ship. In determining fatigue in detailed structures, it can occur in welded joints, section cuts and shape imperfections.

Keyword: Review, Fatigue Analysis, Loads, Structural Details, Ship

Introduction

Structures or components that experience an average tensile force are at risk of static failure when they encounter stresses that exceed their capacity in certain areas [1]. However, the situation is slightly different when structures go through repeated loads. Even though the average stress level is low, local stress concentrations can trigger failure due to fatigue. It is caused by material failure due to fatigue, which depends on the maximum stress value and not the average stress. Studying stress concentration becomes crucial in structures subjected to repeated loads, such as planes, ships, bridges, and machines.

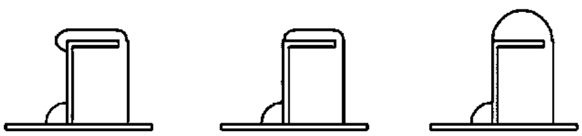
Stress concentrations are caused by discontinuities in holes, such as shafts, hatch openings, superstructures, or welded joints on ships [2]. It is difficult to eliminate stress concentrations from structures experiencing discontinuities, but it can be reduced. The concentration of factors in the plate floor structure contributes to stress significantly enough to cause the failure of the structure [3]. The proof of this theory is described in a perforated plate experiment by validating the results with empirical calculation [4]. It is known that differences in geometric shapes [5], types of loading and material conditions influence the failure process in structures [6]. Considerations in determining the shape of a structure are very influential in determining its strength and resistance in facing loads.

Based on several previous studies, the geometric shape of a ship's structural details significantly influences the lifespan of a structure. On the other hand, failure can also be caused by imperfections in a production process, which can cause initial cracks to appear. The approach process used as an assumption to analyze fatigue is interesting to discuss. This paper will further process critical reviews analyzed in a critical review study on ship structural details in assessing fatigue conditions.

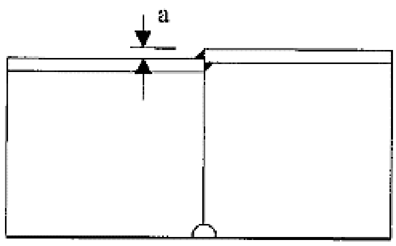
Methodology

1. Ship Structural Details

When designing and producing a ship, it is imperative to pay close attention to the detailed structure of the vessel. The opening in the hull structure is an example of a structural detail that demands careful consideration, along with plates, knees, beam brackets, cutouts or scallops, end connections, manholes, and more [7]. Prior experience in the design process can be highly advantageous. To illustrate various examples of ship structural designs, please refer to Figure. 1.



(a)



(b)

Figure. 1 Structural Details: (a) Scallop Design; (b) Misalignment on Girder

This figure shows a cutout type used for longitudinals through non-tight structures to reduce stress. The details of the structure are designed to have a dimensional radius and distance to the stiffeners, to ensure proper load distribution and restrain force reaction capacity. Misalignment imperfection tends to cause shear stress, especially at the connection points between profiles, which are uneven and give rise to stress concentrations.

2. Loading Conditions

Several variations in repetitive loads cause fatigue; on ship structures in particular, repetitive loads that occur are divided into three categories based on the frequency of occurrence, namely:

- Loading due to varying conditions,
- Loads in a seaway.
- Load by vibrations induced.

According to Fricke [8], load conditions in material fatigue can be grouped into several categories above. These loading conditions are greatly influenced by the load conditions that occur. Cyclic loads on structures can be recorded and simulated based on environmental conditions [9]. The load simulation results based on environmental conditions can be seen in Figure 2.

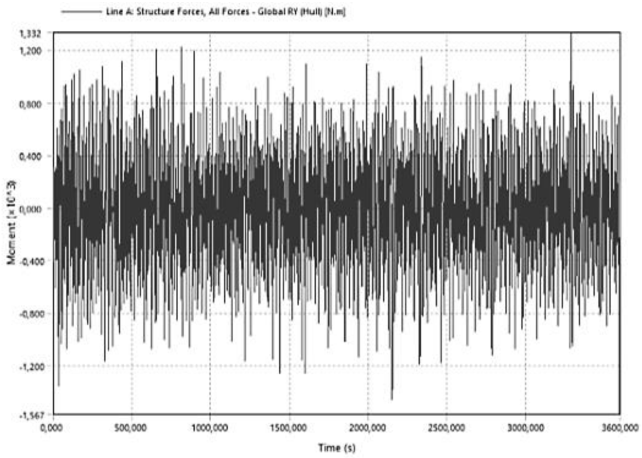


Figure 2. Dynamics Load History

Utilizing existing environmental conditions, we can confidently model the conditions and determine the necessary parameters. By effectively formulating the type of event variable in Equations (1):

$$\Delta\sigma = \sigma_{max} - \sigma_{min} \quad (1)$$

There are two types of loading in the stress range case: Constant-Amplitude Loading and Variable Amplitude Loading. The way Variable-Amplitude Loading works is different from the way Constant-Amplitude Loading works. This is because Variable-Amplitude Loading has a very complex function, where the probability of the magnitude of the stress range during the time interval is very small.

3. Fatigue Strength Assessment

In ship structures, fatigue assessment of materials can be carried out using several methods, the main thing is to carry out a limit state design to determine the risks that can occur in the ship's hull structure [10]. In the modeling, the ship's hull is given the largest load, in this case the bending moment load due to calm water and the bending moment load due to waves [11]. The fatigue calculation approach for ship structural details can be carried out based on rules to determine critical load locations [12]. The approach to determining failure in a structure can be tested using laboratory-based data using the stress life or strain life method and can be predicted using fracture mechanics as was done in previous research [5].

Stress-life can be used by carrying out several tests with detailed loading according to the rules to see how failure in the materials occurs. Meanwhile, the method used for crack propagation will go through several mechanical stages until the material fails [13]. The mechanism of material fracture begins with three modes: compressive, tensile load, shear load, and torsional load [14]. Details figure able to represent that load level should be shown in Figure 3. In addition, numerical approach methods have also been widely used. The requirement for determining this is knowing the S-N curve of the material to be tested. Based on the material testing process, the nominal stress, hot spot stress, and stress concentration conditions that occur are reviewed. However, in the case of complex geometry, this approach can be modelled using Finite Element Analysis (FEA).

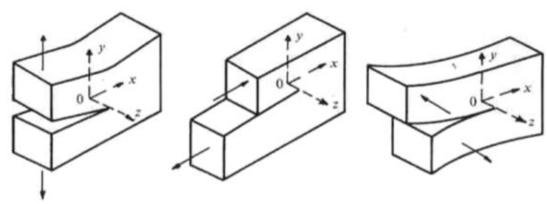


Figure 3. Fracture Mechanics Mode

Fatigue can also be determined using a spectral-based analysis approach by paying attention to environmental data, which is used as input time history as a load. The load distribution can be transferred to local structures. In solving the conditions of this approach, it is necessary to model the global structure to determine the response to the environment [15].

4. Case Study in Influencing Factors

This review discusses several cases to find out how failure conditions in materials can occur. The first is how the details or cut-out structure experiences failure, which refers to research [3], [5], [16]. The shape of the structure in the scallop penetration affects the condition of strength and resistance to cyclical loads, thus affecting the age of the structural details.

Further discussion was carried out on structural conditions that experienced misalignment. In this condition, several connection angles were varied to overcome excessive stress in the connections, which could fail the structure.

Result and Discussion

The selection of the ship's structural design significantly influences the results of stresses and deformations in the structure. Even though the detailed structure is not the main reinforcement, its presence in providing reinforcement must be considered.

Ship structural details will protect the main structure in diverting stress concentrations. In this case, its use must be considered properly to not increase the risk of damage.

The discussion referring to structural modelling with scallop variations and misalignment in Figure. 1 is the discussion that is determined this time. Using examples is chosen based on the consideration that analysis has been carried out on the structure. In the three scallops, the best design accommodates the radius at the end of the profile so that stress can be distributed properly. The results of the nominal stress analysis resulting from each scallop structure show a relatively similar pattern, namely 52.12 MPa, 51.49 MPa, and 48.40 MPa at the largest stress, this difference in stress has a significant impact on fatigue.

Furthermore, the misalignment conditions are modelled using finite element modelling to determine the magnitude of the stress. In this case, it shows directly that the influence of imperfection has a big effect and impact on the reaction to the forces acting, in this case, the girders on the patrol ship. The misalignment modelling image can be seen in Figure. 4. Based on the analysis, the results of the load analysis carried out on the structure against the stresses that occur. After being compared with the minimum criteria, misalignment conditions exceeding 3 mm do not meet the minimum criteria for strength in the structure, which can fail when facing operational loads. Detailing from this analysis can be shown in Table 1 the details acceptance criteria from classification rules.

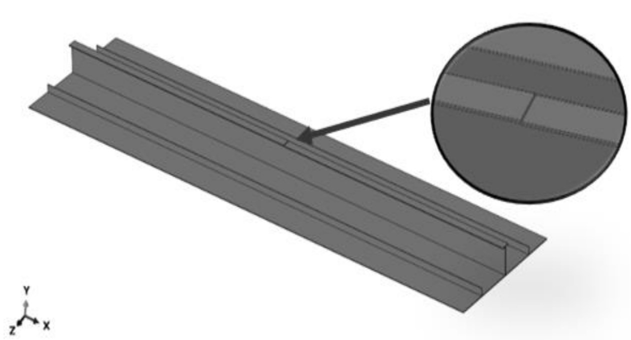


Figure. 4 Misalignment model on Girder Structure

Table 1. The results from Misalignment Analysis

Misalignment (mm)	Stress (MPa)		Remarks
	Analysis Results	Acceptance Criteria	
0	94,013	226,596	
0,5	95,649	226,596	OK
1	96,026	226,596	OK
1,5	179,900	226,596	OK
2	203,400	226,596	OK
2,5	224,300	226,596	X
3	242,900	226,596	X
3,5	259,500	226,596	X
4	274,000	226,596	X
4,5	286,900	226,596	X
5	298,200	226,596	X

Conclusion

Free In conclusion, Fatigue is a failure that can occur in a ship's hull structure that occurs during the design, production, and operation processes. The first step to prevent fatigue is to know the loads acting on the structure during operations. Besides that, fatigue in ship structural details is very prone to occur. Many factors, such as geometrical discrepancies and imperfections during production, can reduce fatigue strength. So, detailed analysis is needed that arises as a result of operational processes; besides that, an appropriate analysis approach is needed to obtain precise and accurate results that can represent actual conditions.

Different approaches can be considered and adjusted to operational and calculation needs. Determining effective methods is still needed and needs to be improved now and beyond.

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