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Technical and Operational Analysis of Marine Airbag-Assisted Ship Docking

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ABSTRACT – Ship docking operations require careful planning and precise implementation to ensure safety and operational efficiency. One widely applied method in shipyard practice is the use of marine airbags to support vessels during docking and undocking processes. This study analyzes the application of a marine airbag-assisted docking system for the barge *BG. Liana* at PT. Jhonlin Marine Trans using an analytical and field-based approach. The analysis focuses on determining the required number of airbags, evaluating load distribution, and identifying factors contributing to airbag failure during docking operations. Vessel principal dimensions and marine airbag specifications were used as primary input parameters, while field observations were conducted to assess actual operational conditions. The results indicate that a minimum of 21 marine airbags is required to ensure adequate load sharing and structural safety; however, only seven airbags were deployed in practice, leading to excessive load concentration and increased risk of airbag failure. The failure analysis demonstrates that the observed damage was predominantly caused by controllable operational factors, including inadequate airbag quantity, improper placement, pressure inconsistencies, and runway conditions. These findings highlight the importance of strict compliance with analytical planning and operational procedures to enhance safety and reliability in marine airbag-assisted docking operations.

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INTRODUCTION

Ship launching represents one of the most critical phases in ship construction because technical errors or operational deviations may cause hull deformation, water ingress, or uncontrolled vessel movement, which can lead to serious safety hazards and operational losses [1]. This process involves substantial structural loads, complex contact mechanics, and inherent workplace risks that directly influence vessel integrity and worker safety [2]. Numerical analyses have shown that arrays of marine airbags undergo nonlinear deformation and evolving contact interactions during launching, resulting in highly variable load paths and localized pressure distributions that are sensitive to the positioning and sequencing of the airbags [2]. Experimental tests and finite element analyses have further demonstrated that airbag-induced loading can generate significant localized stresses on the hull structure. Longitudinal tensile stresses of approximately 87.3 MPa and compressive stresses of around 50.2 MPa have been reported under simulated launch conditions, emphasizing the structural risks associated with improper load management [3].

To mitigate these risks, marine airbag-based launching and docking systems have been increasingly adopted, particularly in shipyards with limited infrastructure. Airbags function as flexible load-distributing supports that facilitate hull movement during launching or retrieval, offering notable advantages in adaptability and cost efficiency compared with conventional slipway systems [4]. Prior studies indicate that airbag-assisted launching can reduce working hours by approximately 44 percent and improve time effectiveness by up to 84 percent, although conventional slipways may still offer lower capital investment in certain contexts, with potential savings of about 43 percent [4]. These systems are further supported by engineering design tools and validated computational programs capable of performing rigidity assessments, comparative scheme evaluations, and safety analyses for launch planning [5].

Despite these advantages, the performance of marine airbags is highly dependent on appropriate load distribution, internal pressure regulation, equipment condition, and rigorous adherence to operational procedures

[2], [6]. Airbag arrays exhibit nonlinear interaction and variable load-transfer behavior during vessel movement, producing uneven deformation and concentrated reaction forces when improperly arranged [2]. Accurate inflation and staged pressure adjustment are essential for maintaining stability, and experimental research indicates operational pressure ranges between 0.175 and 0.375 bar during sequential launch phases. Variations in pressure have been shown to influence stern lift, trim behavior, and hull support reactions [6]. Material condition also plays a critical role because rupture analyses rely on strain-based and burst criteria, and advanced failure models, including Hashin-type criteria, have been applied to evaluate delamination and burst behavior under dynamic loading [7], [8]. Operational factors such as airbag positioning, inflation sequencing, and slipway surface preparation additionally influence load paths and overall system stability [2], [5].

In practical shipyard environments, deviations from recommended procedures, deterioration of materials, and surface irregularities frequently contribute to airbag rupture incidents. Field studies report that although airbag-based launching is generally safer than uncontrolled launching methods, significant hazards persist when operational controls are inconsistently implemented [9], [10]. Common contributors to failure include incorrect inflation sequencing that generates unstable lifting moments, uneven slipway surfaces that create localized overstress, and material degradation or manufacturing defects that reduce allowable strain capacity [2], [6], [7], [8]. These conditions demonstrate that theoretical design considerations alone are insufficient to guarantee safe and reliable airbag-assisted operations.

Previous research has largely concentrated on the mechanical response and load-bearing performance of marine airbags under controlled laboratory or numerical conditions, emphasizing nonlinear modeling, experimental loading tests, and finite element simulations of burst behavior [2], [3], [7], [8]. Although these studies have substantially advanced understanding of airbag mechanics, comprehensive empirical investigations that document failure modes and causal patterns within operational shipyard environments remain limited [9], [10]. This limitation underscores the need for technical and operational forensic analyses that link modeled failure mechanisms with real-world rupture cases.

The present study addresses this need by conducting a detailed technical and operational investigation of marine airbag failure during the docking operation of the vessel BG Liana at PT. Jhonlin Marine Trans. Through field observations, operator interviews, vessel technical data, and airbag specifications, this study identifies the dominant factors contributing to airbag rupture and proposes preventive measures to minimize failure risk and enhance safety performance in shipyard operations. By examining an actual failure case, the study provides empirical evidence that strengthens the connection between analytical predictions and practical outcomes, thereby contributing to the development of more robust operational protocols for marine airbag-based launching and docking systems.

METHODS

This study employs an analytical and field-based calculation method to evaluate the adequacy of marine airbag deployment during ship docking operations. The method focuses on quantifying the required number of airbags based on vessel principal dimensions, docking weight, and airbag load capacity, followed by a comparison with actual operational conditions observed at the shipyard.

Table 1. Principal Dimensions of the Vessel

Parameter	Ukuran
LOA (Length Overall)	100,58 m
L (Length)	96,56 m
B (Breadth)	24,26 m
D (Depth)	5,49 m

The object of this study is the docking and undocking operation of the barge *BG. Liana* conducted at PT. Jhonlin Marine Trans using a marine airbag-assisted method. The vessel represents a typical barge-type ship operated under shipyard docking conditions.

Table 2. Marine Airbag Specifications

Diameter (m)	Working Pressure (MPa)	Working Height (m)	T/m	lb/ft
0,8	0,30	0,5	188.65	12936
1,0	0,25	0,6	217.85	14936
1,2	0,20	0,7	216.62	14892
1,5	0,15	1,0	200.01	13716
2,0	0,12	1,2	420.33	29408

The principal dimensions of the vessel used as input parameters for the calculation are presented in Table 1. These dimensions were obtained from ship technical documentation provided by the shipyard. Marine airbag specifications were obtained from field observations and operational records at the shipyard. The available airbag specifications are summarized in Table 2 and include diameter, working pressure, working height, and load capacity.

Based on operational considerations and vessel size, marine airbags with a diameter of 2.0 m and a length of 12 m were selected for the docking operation. This selection balances sufficient load capacity with operational handling, storage efficiency, and compatibility with the vessel dimensions. The required number of marine airbags was calculated using a standard formulation commonly applied in shipyard practice for airbag-assisted launching and docking operations. The calculation is expressed as:

$$N = K_1 + \frac{Q \times g}{Cb \times R \times Ld} + N_1 \tag{1}$$

Where:

Q	=	Vessel Docking Weight (9115.23 ton)
g	=	Gravitational acceleration is (9,8 m/s^2)
Cb	=	Block Coefficient is (0,89)
R	=	Unit bearing capacity of the airbag is (475,51 ton/m)
Ld	=	Effective length of airbag contact is (12 m)
K_1,N_1	=	Safety coefficients

RESULTS AND DISCUSSION

Based on the analytical formulation, the required number of marine airbags for the docking and undocking operation of the barge *BG. Liana* was determined using actual vessel and airbag parameters obtained from shipyard records. The calculation was performed to evaluate whether the operational implementation met the minimum technical requirements for safe load distribution

The numerical calculation results show that the product of the vessel docking weight and gravitational acceleration yields a load term of

$$Q \times g = 9115.23 \times 9{,}8 = 89329.254 \tag{2}$$

Meanwhile, the combined capacity term derived from the block coefficient, airbag load capacity, and effective airbag length is given by

$$Cb \times R \times Ld = 0{,}89 \times 475{,}51 \times 12 = 5078.45 \tag{3}$$

The ratio between the load term and the capacity term results in a value of :

$$\frac{A}{B} = \frac{89329.254}{5078.45} = 17.589 \tag{4}$$

After applying correction factors (N_1 = 2, Safety Factor K_1= 1.2), the final required number of airbags is[16]:

$$N = 1{,}2 + 17.589 + 2 = 21 \text{ unit} \tag{5}$$

This result indicates that a total of 21 marine airbags is required to ensure adequate load sharing and structural safety during docking and undocking operations of the vessel.

Figure 1. Marine airbag-assisted docking operation of BG. Liana

Field observations conducted at PT. Jhonlin Marine Trans indicate that the actual docking operation of *BG. Liana* was carried out using only seven marine airbag units, which is significantly lower than the analytically determined requirement. This discrepancy results in an excessive load being borne by each active airbag.

From a mechanical and structural standpoint, reducing the number of airbags directly increases the load per unit, leading to uneven load distribution along the hull. Such conditions promote localized stress concentration on the airbag surfaces and significantly elevate the risk of airbag deformation and rupture during the docking process. The mismatch between calculated requirements and operational practice therefore represents a critical technical deficiency in the docking implementation.

To identify the causes of airbag failure, operational conditions observed during docking were systematically analyzed and classified based on their level of controllability. The identified contributing factors are summarized in Table 3.

Table 3. Factors Contributing to Marine Airbag Failure

No	Contributing Factor	Risk Type	Technical Description
1	Airbags in patched condition	Controllable	Reduction in structural integrity, increasing susceptibility to rupture under elevated pressure
2	Excessive internal air pressure (overpressure)	Controllable	Pressure exceeding recommended limits, causing excessive deformation
3	Improper airbag positioning	Controllable	Uneven load distribution leading to localized stress concentration
4	Uneven and inadequately compacted runway	Controllable	Increased frictional resistance and additional mechanical loading
5	Damaged or sharp hull bottom plates	Uncontrollable	Direct mechanical tearing of airbag material during initial contact
6	Insufficient number of airbags (7 of 21 required)	Controllable	Load imbalance resulting in excessive stress on available airbags

The summarized results confirm that the deviation from the required number of airbags was the primary trigger of the structural failure. The situation was further worsened by the use of patched airbags, the absence of valid pressure-test certificates, and the presence of sharp objects along the runway surface. These conditions demonstrate that the operational safety controls were not implemented through systematic engineering procedures and largely depended on operator judgment.

To mitigate the gap between theoretical engineering requirements and actual field practices, this study proposes a structured mitigation framework based on the principles of Hazard Identification, Risk Assessment, and Risk Control (HIRARC) and aligned with the AS/NZS 4360 risk management standard. The framework introduces a shift from estimation-based decision-making to a formal, documented, and verifiable risk assessment process. A detailed risk matrix must be developed for every docking procedure to classify hazards such as airbag ruptures, winch overload, trim imbalance, and uncontrolled hull movement while assigning appropriate preventive actions.

To prevent recurrence of operational failures, the study identifies several Critical Control Points (CCPs) that must be satisfied before vessel lifting activities are conducted. The first CCP requires verification that the number of airbags deployed matches the calculated requirement. A discrepancy between required and deployed quantities must automatically trigger a No-Go decision. The second CCP involves verification of material integrity through updated pressure-test certificates, ensuring that patched or degraded airbags are not utilized in critical load-bearing regions such as the bow and stern lift-off points. The third CCP requires full runway standardization, ensuring that the entire contact surface is cleared of sharp or abrasive objects and properly leveled to eliminate localized puncture stresses.

A pre-operational inspection checklist is proposed to ensure systematic verification of equipment readiness. The checklist includes the evaluation of physical airbag condition, pressure system integrity, and slipway preparation. Physical inspections must confirm the absence of visible cuts, blisters, or abrasions, while pressure system inspections must verify calibration of gauges and functionality of relief valves. A pre-inflation test is necessary to ensure a leak-free system. Site preparation includes clearing the runway surface, compacting and leveling the pathway, and installing protective layers at contact points. Documentation must also verify alignment between calculated and deployed airbag quantities and confirm the execution of safety briefings related to operational roles, communication protocols, and emergency stop procedures.

During operation, staged inflation procedures must be implemented with continuous monitoring of hull trim and airbag behavior. Operational personnel must identify early indicators of potential failure, such as membrane bulging or audible seam noises. In the event of instability or rapid pressure loss, the procedure must transition to an immediate stop condition. If feasible, controlled deflation must be performed to safely return the vessel onto secondary supports, thereby preventing cascading airbag failure and potential structural damage.

CONCLUSION

This study was conducted to evaluate the compliance of the marine airbag-assisted docking operation of the barge BG Liana with engineering requirements, operational safety standards, and analytical calculations governing load distribution. The findings indicate that the operation did not meet the minimum technical criteria established through analytical assessment, which determined that twenty-one airbags were necessary to achieve safe and uniform load sharing. In practice, only seven airbags were deployed, resulting in disproportionate load transfer to individual units and heightened stress concentrations along critical lifting zones. This condition was further aggravated by operational deficiencies including the use of degraded or patched airbags, improper internal pressure control, inaccurate positioning, and inadequately prepared runway surfaces. Collectively, these factors compromised the structural integrity of the airbag system and substantially increased the likelihood of failure. The results affirm that the dominant failure mechanisms were controllable and arose primarily from procedural non-compliance rather than inherent material limitations. Accordingly, the objectives of this research are addressed by demonstrating that 1) engineering-based calculations must be strictly adhered to in order to prevent overload conditions, 2) systematic inspection and material verification are essential to maintaining airbag reliability prior to deployment, and 3) operational management must be strengthened through structured planning, standardized procedures, and improved operator competency. Overall, the study underscores that marine airbag-assisted docking can achieve safe and effective performance only when technical specifications, operational discipline, and risk control measures are rigorously implemented.

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