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Sea-Fastening of Cargos on a Platform Support Vessel Using Lashing Method

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***Abstract*: This study examines the critical aspects of sea-fastening methodologies for securing cargo on Platform Support vessels, integrating theoretical principles, practical load plan results, and equipment certification. The methodology emphasizes a systematic approach encompassing data collection, force calculation, lashing plan design, execution, and verification, all crucial for ensuring cargo stability and vessel safety during maritime transport. The theoretical framework, rooted in Newton's laws of motion, analyzes static, dynamic (induced by vessel motions like roll, pitch, and heave), and environmental forces acting on cargo. Basic equations for inertial force, frictional force, overturning moment, and righting moment underpin the design and analysis of securing arrangements. The load plan results for twelve distinct loads reveal calculated maximum forces ranging from 10.1229 N to a critical high of 205.7179 N for specific loads (4 and 7). Correspondingly, lashing tensions were applied based on these forces, utilizing both single and dual belts at 50% (12500 N) and 75% (18750 N) of their strength, demonstrating a risk-adjusted securing strategy. The relatively consistent maximum acceleration values (around 0.10-0.11 m/s²) across loads indicate the significant influence of vessel motion on the forces experienced. The certification of a cargo lashing belt with a capacity of 2500 daN (25000 N) and the visual confirmation of such belts in practical application underscore the importance of using inspected and compliant equipment. The analysis highlights the necessity of addressing critical high-force loads with enhanced securing measures, as evidenced by dual lashings. Integrating a robust methodology, informed by theoretical calculations and validated through practical application with certified equipment, is paramount for ensuring the safe and secure cargo transportation at sea, mitigating risks to the vessel, crew, and the cargo itself. This study emphasizes the interplay between meticulous planning, accurate force assessment, and the appropriate application of securing equipment to achieve effective sea-fastening.**

***Keywords*: Sea-fastening, Lashing, Cargo Securing, Vessel Motion, Dynamic Forces, Static Forces, Acceleration, Inertial Force, Lashing Tension, Belt Strength, Safety Factor, Load Plan, Center of Gravity (COG), Minimum Breaking Load (MBL), Marine Warranty Surveyor (MWS), Platform Support Vessel.**

1. Introduction

The document starts here. Copy and paste the content in the paragraphs. The safe and efficient cargo transportation by sea is a cornerstone of global commerce and offshore operations. However, the dynamic marine environment significantly challenges maintaining cargo integrity during transit. The ever-present forces of waves, wind, and vessel motion can induce substantial stresses on cargo loads, leading to potential damage, loss, or even catastrophic incidents if proper securing measures are not implemented [2]. Among the various sea-fastening techniques, lashing remains a widely utilized and adaptable method, particularly for securing diverse cargo types on Platform Supply Vessels (PSVs) and other marine transport vessels.

This paper delves into the critical aspects of vessel load sea-fastening using lashing, focusing on the methodologies and considerations necessary to ensure safe and effective cargo securing. Unlike rigid securing systems, lashing offers flexibility in accommodating complex load geometries and is often preferred for its adaptability and cost-effectiveness. However, its efficacy hinges on a thorough understanding of the dynamic forces at play, the proper selection of lashing materials, and meticulous execution of securing procedures [3].

The maritime industry has witnessed numerous incidents resulting from inadequate sea-fastening, underscoring the necessity for rigorous engineering analysis and standardized practices [4]. This paper aims to provide a comprehensive overview of the principles governing load sea-fastening, including calculating static and dynamic forces, determining appropriate lashing strengths, and implementing effective lashing patterns. By examining the interplay between vessel motion, cargo characteristics, and environmental conditions, this work seeks to enhance the understanding of sea-fastening best practices and promote safer marine transportation.

Furthermore, this paper investigates the application of computational methods and industry guidelines in sea-fastening calculations, ultimately contributing to developing more robust and reliable securing strategies. It also addresses integrating factors such as cargo center of gravity, vessel motion parameters, and wind loads into the analysis [1]. Valuable insights are provided for marine engineers, naval architects, and maritime professionals involved in cargo transportation and offshore operations.

Ultimately, the goal of this paper is to contribute to the advancement of knowledge in sea-fastening practices, thereby fostering safer and more efficient marine transportation of cargo. By highlighting the critical role of lashing in ensuring

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cargo integrity and vessel safety, this work aims to promote the adoption of robust sea-fastening strategies and mitigate the risks associated with marine cargo transportation.

2. Methodology

A robust methodology for lashing and sea-fastening on vessels is crucial for ensuring the safe transport of cargo. This process begins with meticulous data collection and analysis. Detailed cargo data is essential, including the weight, dimensions, shape, and center of gravity (COG) for each item. Information on material properties, structural integrity, lifting points, and lashing suitability is also vital. Vessel-specific information, such as the deck layout, available lashing points, vessel motion characteristics (roll, pitch, heave, periods, and angles), stability data (KG, GM), and loadline details, must be obtained. Furthermore, gathering environmental data, including weather forecasts (wave height, period, wind speed, and direction), the voyage route, potential hazards, and water density, is necessary for a comprehensive understanding of the forces the cargo will endure.

The next step involves a series of calculations to determine the forces acting on the cargo. Static forces, resulting from gravity and vessel inclination (roll and pitch), are calculated. Dynamic forces, caused by vessel motions (roll, pitch, and heave), are determined using appropriate formulas or software, accounting for accelerations and inertial forces. Wind forces on the cargo's exposed surfaces are also calculated. These static, dynamic, and wind forces are combined to determine the total forces acting on the cargo. Based on these total forces and relevant safety factors, the required Minimum Breaking Load (MBL) of the lashing is calculated, considering the lashing angle and efficiency. Finally, these forces are converted into acceleration values to understand their effects on the cargo better.

With the forces determined, sea-fastening planning and design can proceed. A detailed lashing plan specifies the lashing type and arrangement (direct, indirect, cross, loop, top-over), the number and placement of lashing points, and the lashing angles and tensioning requirements. The cargo's shape, weight distribution, and potential movement are carefully considered. Appropriate lashing materials, such as wire rope, chain, or synthetic webbing, are selected based on the MBL and environmental conditions. Suitable securing devices, including turnbuckles, shackles, and eye bolts, are chosen. The use of dunnage and protective materials to prevent damage to both the cargo and the lashing is specified. Detailed sea-fastening drawings and instructions are created to guide the execution phase.

The execution and implementation phase involves several critical steps. A pre-loading inspection of the vessel's deck, lashing points, and lashing equipment is conducted. Cargo is loaded according to the stowage plan, ensuring proper weight distribution. Lashing is installed according to the sea-fastening plan, with careful attention to proper angles and tension. Lashings are tensioned evenly using appropriate tools, and all securing devices are properly secured. Throughout this process, detailed records of all lashing details are maintained, and photographs are taken for documentation purposes.

The final stage is inspection and verification, which ensures the effectiveness of the sea-fastening. A pre-departure inspection is conducted to verify lashing tension and integrity. During transit, regular inspections are performed, especially after encountering rough weather, to check lashing tension and make necessary adjustments. Upon arrival, a final inspection is carried out to document any damage or cargo movement. When required, a Marine Warranty Surveyor (MWS) is involved in all stages, from planning to inspection, to provide an independent assessment and ensure compliance with industry standards and best practices.

A. Principle and Theory of Sea-Fastening

The principle behind sea-fastening a load to a vessel's deck is to secure the cargo in such a way that it resists the forces encountered at sea, thereby preventing movement that could damage the cargo, the vessel, or endanger the crew. The theory relies on fundamental principles of physics, primarily Newton's laws of motion, to analyze the forces acting on the cargo and to design securing arrangements that counteract these forces.

The core principle of sea-fastening is to ensure the stability and immobility of the cargo relative to the vessel under all anticipated sea conditions. This involves:

1. *Preventing sliding*: Restraining the cargo against horizontal forces that can cause it to slide across the deck.
2. *Preventing tipping/overturning*: Ensuring the cargo's center of gravity remains within a stable base, resisting rotational forces.
3. *Preventing lifting/uplift*: Securing the cargo against vertical forces that could lift it off the deck.
4. *Distributing loads*: Ensuring the weight of the cargo is spread evenly across the deck structure to avoid exceeding its load-bearing capacity.
5. *Maintaining the vessel's stability*: Preventing significant cargo shifts that could negatively impact the vessel's stability and trim.

The theory behind sea-fastening involves analyzing the various forces that will act on the cargo during a sea voyage. These forces can be broadly categorized as:

1. *Static Forces*: Weight (Gravity): The constant downward force acting on the cargo's mass (($W = mg$) where (m) is mass and (g) is the acceleration due to gravity).
2. *Dynamic Forces (due to vessel motions)*: The vessel at sea undergoes six degrees of motion:
   a. *Linear Motions:*
      i. *Heave*: Vertical up and down motion.
      ii. *Sway*: Lateral (side-to-side) motion.
      iii. *Surge*: Longitudinal (forward-backward) motion.
   b. *Rotational Motions:*
      i. *Roll*: Rotation about the longitudinal axis (side to side tilting).
      ii. *Pitch*: Rotation about the transverse axis (bow up and down).

iii. *Yaw*: Rotation about the vertical axis (turning motion).

The rotational and vertical linear motions (roll, pitch, and heave) are the most significant contributors to the dynamic forces acting on the cargo. These motions induce accelerations at the location of the cargo, resulting in inertial forces ((F = ma) where (a) is the acceleration). These accelerations have components in the vertical, transverse, and longitudinal directions relative to the vessel.

Vertical Acceleration (a_v): Caused by heave and the vertical components of roll and pitch. This affects the effective weight of the cargo and the friction between the cargo and the deck.

a. Transverse Acceleration (a_t): Primarily caused by roll and sway, and the transverse component of heave during rolling. This is a critical force for preventing sliding and tipping.
b. Longitudinal Acceleration (a_l): Primarily caused by pitch and surge, and the longitudinal component of heave during pitching. This needs to be considered to prevent sliding in the fore-aft direction.
c. Angular Accelerations ((alpha)): Caused by roll and pitch, these accelerations, combined with the distance from the axis of rotation, also contribute to linear accelerations at the cargo's center of gravity.

3. *Environmental Forces*
   a. *Wind Forces*: Pressure exerted by the wind on the exposed surfaces of the cargo.
   b. *Green Sea Forces*: Impact forces from waves washing over the deck. These are particularly significant for cargo stowed on open decks.

B. Basic Equations

The basic equations used in sea-fastening calculations typically involve applying Newton's second law ((F = ma)) to the cargo in various directions, considering the accelerations induced by the vessel's motions and environmental loads. Here are some fundamental concepts and related equations:

1) Inertial Force

$$F_i = {}^{m}/_{a} \tag{1}$$

Where:
F_i is the inertial force
(m) is the mass of the cargo
(a) is the acceleration of the cargo due to vessel motion (can be (a_v), (a_t), or (a_l))

2) Frictional Force

$$F_f = \mu/F_N \tag{2}$$

Where:
(F_f)is the maximum static frictional force.
(μ) is the coefficient of static friction between the cargo and the deck (or dunnage).
F_N is the normal force (typically related to the effective weight of the cargo, considering vertical accelerations:

3) Overturning Moment

$$M_{ot} = F_h \times h_{cg} \tag{3}$$

Where:
(M_r) is the righting moment
(W) is the weight of the cargo.
(d) is the distance between the line of action of the weight and the edge of the base (the lever arm).

For stability against tipping, the righting moment must be greater than the overturning moment, often with a safety factor.

4) Forces in Securing Devices (Lashings, Chocks, etc.)

These calculations involve resolving the inertial and environmental forces into components acting on the securing devices at their attachment points. The tensile or shear forces in these devices must be within their safe working load limits. This often involves trigonometry to account for the angles of the lashings.

C. More Advanced Considerations

More detailed calculations may involve:

1. *Motion Prediction*: Using the vessel's characteristics, loading condition, and anticipated sea state to predict the magnitudes and frequencies of the vessel's motions and the resulting accelerations at the cargo location.
2. *Load Factors*: Applying safety factors to account for uncertainties in motion prediction, cargo properties, and the strength of securing materials.
3. *Dynamic Analysis*: For complex or heavy lifts, dynamic analysis using software tools may be employed to simulate the forces and stresses during transit.
4. *Class Society Rules and Guidelines*: Adhering to the specific requirements and guidelines provided by classification societies and regulatory bodies for cargo securing.

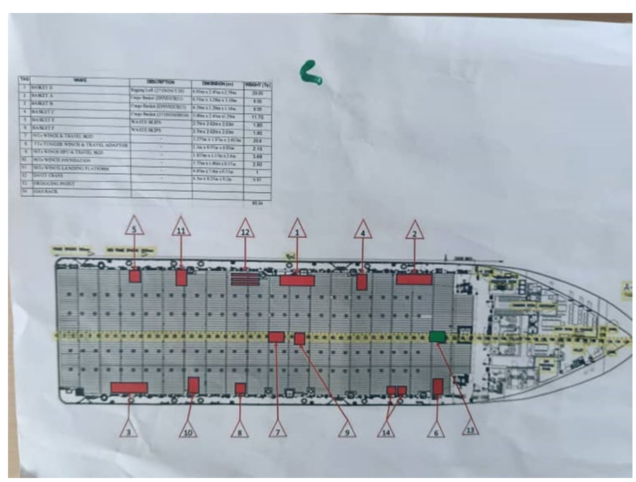


Fig. 1. Layout plan for the PSV vessel

Figure 1 shows a load plan diagram for a Platform Support Vessel (PSV) with a structured approach to cargo stowage. The accompanying table details a diverse range of cargo items, varying significantly in weight and dimensions, from the heavy "TARGET A" at 20 tonnes to lighter components. The deck layout visually maps the intended positions of these items, numbered 1 through 14 and represented by red rectangles, alongside a distinct green rectangle at the stern (position 15). Strategically placed triangular symbols along the vessel's Port and Starboard sides, numbered 1 through 12, likely indicate the locations and potentially the capacity of available lashing points for securing the cargo.

An initial assessment of the load plan suggests weight distribution and cargo dimensions considerations. Heavier items, such as "TARGET A," are positioned relatively forward, a common practice to enhance stability. Longer cargo is generally aligned longitudinally, minimizing overhang. Furthermore, there is an effort towards symmetrical loading across the vessel's beam, which is crucial for maintaining transverse stability and reducing the risk of excessive rolling during transit. The lines connecting the red cargo rectangles to the triangular lashing points visually represent the planned securing arrangements for each item, highlighting the integration of cargo placement with lashing possibilities.

The load plan diagram provides a valuable visual framework for cargo stowage on the PSV; a thorough understanding of its safety and efficacy requires a review of the underlying engineering calculations, lashing specifications, and stability assessments. Factors such as the use of dunnage, the types of securing devices to be employed, and adherence to relevant maritime regulations and potential Marine Warranty Surveyor (MWS) requirements would further contribute to a complete evaluation of the robustness of this sea-fastening methodology.

3. Results and Discussion

Table 1 presents a summary of sea-fastening load calculations for twelve distinct loads (numbered 1 to 12) secured to the deck of a vessel. It provides key values for assessing the effectiveness and safety of the lashing arrangements. The columns detail the maximum calculated force acting on each load (in Newtons), the maximum acceleration experienced by each load (in unspecified units, but likely m/s² based on the context of force and mass), and the lashing tension applied to each load, expressed in Newtons and as a percentage of the belt's strength.

The "Max Calculated Force" column indicates the peak forces that the lashing system for each load is expected to withstand during the voyage, considering static and dynamic loads induced by vessel motions and environmental factors. Loads 4 and 7 exhibit significantly higher calculated forces (205.7179 N and 203.1546 N, respectively) compared to the other loads, suggesting they are either heavier, more exposed to dynamic forces, or have a higher centre of gravity. The "Max Acceleration of Each Load" column shows relatively consistent acceleration values across all loads, ranging from approximately 0.1019 to 0.1076. This suggests that the vessel's motion characteristics are impacting all the loads similarly in terms of acceleration.

The "Lashing Tension (N) By % of Belt Strength" column is critical for evaluating the safety margin of the sea-fastening. For loads 1, 2, 3, and 7, a lashing tension of 18750 N is applied, utilizing 75% of the belt's strength. This indicates a substantial securing force and a remaining safety margin of 25% before reaching the belt's capacity. Loads 4 and 7 utilize two belts at this tension, increasing their securing capacity due to the higher calculated forces. The remaining loads (5, 6, 8, 9, 10, 11, and 12) have a lashing tension of 12500 N, utilizing 50% of the belt's strength, providing a larger 50% safety margin.

A. Critical Values and Observations

High Force Loads (4 & 7): The significantly higher calculated forces on loads 4 and 7 are critical values that necessitate using two lashing belts at a higher tension (75% of strength) to ensure adequate security. These loads warrant careful attention during pre-departure checks and potential in-voyage inspections.

Consistent Acceleration: The relatively uniform acceleration values across all loads suggest that the vessel's motion is a primary driver of the forces, and the lashing system is designed to accommodate these general accelerations. Safety Margins: The utilization of 50% and 75% of the belt strength indicates a planned safety factor in the lashing arrangements. The 50% utilization for the majority of the loads provides a more conservative safety margin.

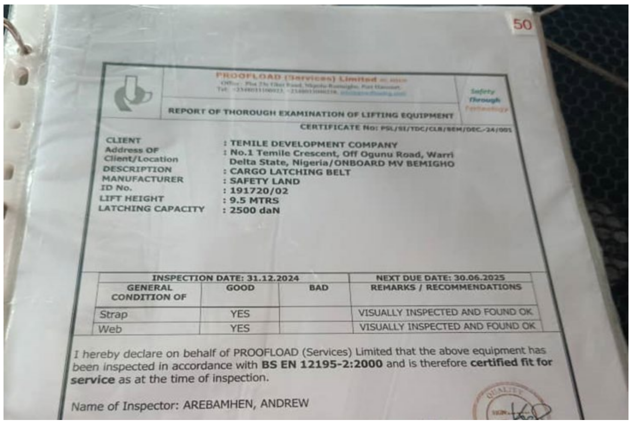
Belt Strength Variation: The table implicitly suggests that at least two different strengths of lashing belts are in use: one with a strength allowing for 18750 N at 75% utilization, and another allowing for 12500 N at 50% utilization. Knowing the actual Minimum Breaking Load (MBL) of these belts would provide a clearer understanding of the overall safety factors.

Figure 2 shows the certificate, issued by Proofload (Services) Limited, documents a thorough examination of lifting

Table 1
Table of calculated force, acceleration and estimated lashing tension by results

	Max Calculated Force (N)	**Max Acceleration of Each Load** m/s^2	**Lashing Tension (N) By % of Belt Strength**
1	98.4014	0.1050	18750N by 75%
2	98.4146	0.1051	18750N by 75%
3	117.9022	0.1027	18750N by 75%
4	205.7179	0.1049	18750N by 75% & 2 belts
5	18.1016	0.1025	12500N by 50%
6	18.1016	0.1025	12500N by 50%
7	203.1546	0.1027	18750N by 75% & 2 belts
8	37.1525	0.1026	12500N by 50%
9	25.3123	0.1032	12500N by 50%
10	10.1229	0.1032	12500N by 50%
11	20.9883	0.1019	12500N by 50%
12	20.5775	0.1076	12500N by 50%

equipment identified as a "Cargo Latching Belt" manufactured by Safety Lifting. The certificate number Prl/Fge/El/Cert/085-Dec/24/085 indicates its unique identification and date of issue as December 31, 2024. The equipment has a lift height of 9.5 meters and a lashing capacity of 2500 daN (decaNewtons), a unit of force commonly used in lashing and cargo securing applications. The inspection, conducted on December 31, 2024, assessed the general condition of the equipment as "Good."



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PROOFLOAD (Services) Limited

Safety Through Technology

REPORT OF THOROUGH EXAMINATION OF LIFTING EQUIPMENT

CERTIFICATE No: PSL/SI/TDC/CLB/BEM/DEC.-24/001

CLIENT	: TEMILE DEVELOPMENT COMPANY
Address OF Client/Location	: No.1 Temile Crescent, Off Ogunu Road, Warri Delta State, Nigeria/ONBOARD MV BEMIGHO
DESCRIPTION	: CARGO LATCHING BELT
MANUFACTURER	: SAFETY LAND
ID No.	: 191720/02
LIFT HEIGHT	: 9.5 MTRS
LATCHING CAPACITY	: 2500 daN

INSPECTION DATE: 31.12.2024			NEXT DUE DATE: 30.06.2025
GENERAL CONDITION OF	GOOD	BAD	REMARKS / RECOMMENDATIONS
Strap	YES		VISUALLY INSPECTED AND FOUND OK
Web	YES		VISUALLY INSPECTED AND FOUND OK

I hereby declare on behalf of PROOFLOAD (Services) Limited that the above equipment has been inspected in accordance with **BS EN 12195-2:2000** and is therefore **certified fit for service** as at the time of inspection.

Name of Inspector: AREBAMHEN, ANDREW

Fig. 2. Lashing belt certification for fitness certificate

Specifically, the components of the lashing belt, namely the "Strap" and the "Web," were both inspected and their condition was noted as "YES," implying they were found to be in satisfactory condition at the time of inspection. The remarks/recommendations section states that both the strap and the web were "Visually Inspected and Found Ok." Based on this examination, the inspector, Arebamhen, Andrew, declared on behalf of Proofload (Services) Limited that the equipment has been inspected in accordance with BS EN 12195-2:2000 and is therefore certified fit for service as at the time of inspection. The certificate bears the signature of the inspector, the official stamp of Proofload Services Ltd, and confirms the inspection date. The next due date for examination is noted as June 30, 2025.

Fig. 3. Lashing belt displaced for physical verification/inspection

Figure 3 displays a collection sea-fastening belts, stored on the deck of a vessel or in a storage area. Several of these belts are tightly coiled, showcasing their webbing material which is predominantly tan or beige with blue reinforcing fibers running along the edges. Each coil has a metal end fitting, likely a ratchet or hook mechanism used to secure cargo. The varying sizes of the coils suggest different lengths or load capacities of the belts. Their somewhat disheveled arrangement on the deck, alongside other miscellaneous equipment, indicates they are either awaiting deployment, have recently been removed after use, or are in a general storage state.

The presence of multiple belts highlights the need for securing various cargo items of different sizes and weights. The condition of these visible belts, while not allowing for a thorough inspection akin to the certified examination, appears to show signs of previous use. Regular inspection and adherence to certification schedules, as indicated by the Proofload certificate with a next due date of June 30, 2025, are crucial for ensuring the continued safety and reliability of these vital sea-fastening components during cargo operations. The physical inspection is to ensure that there is no wear or damaged to the lashing belt before been deployed for use.

Fig. 4. Cargos lashed to the PSV deck using lashing belts

Figure 4 depicts a cargo arrangement on the deck of a PSV vessel, where various pieces of equipment are secured using lashing belts. The equipment, a winch, HPU and blue container are prominently featured. Several tan-colored lashing belts with blue edges are visible, stretched across the cargo and anchored to the deck using yellow square lashing points. These belts are essential for preventing cargo movement during transit, counteracting forces from the vessel's motion and environmental factors such as wind and waves. The Figure shows a practical application of the sea-fastening principles and methodologies previously discussed, where the belts act as restraints to maintain the stability and immobility of the cargo.

The arrangement highlights the importance of proper lashing techniques, as the belts are under significant tension to secure the cargo. The yellow square lashing points are crucial components of the vessel's deck, designed to withstand the forces exerted by the belts. Figure 4 provides a visual context for the lashing belt certificate you shared earlier, demonstrating the real-world use of certified and inspected equipment to ensure cargo safety. The placement and number of belts suggest a careful consideration of the weight and dimensions of the cargo, aiming to distribute the securing forces effectively. This visual representation complements the theoretical understanding of sea-fastening by illustrating how the principles are applied in a practical setting.

4. Conclusion

In conclusion, the comprehensive approach to sea-fastening outlined in the methodology, supported by the theoretical principles and the analysis of the load plan results, underscores the critical importance of a systematic process in ensuring safe maritime cargo transportation. The methodology emphasizes thorough data collection, meticulous force calculations, detailed planning and design of lashing arrangements, careful execution, and rigorous inspection and verification. The results from the load calculation table demonstrate a practical application of these principles, notably highlighting critical values such as the maximum calculated forces of 205.7179 N and 203.1546 N for loads 4 and 7, which necessitated the use of two lashing belts at a higher tension of 75% of their strength. This risk-based approach effectively addresses the higher potential for movement in these specific loads.

The relatively consistent maximum acceleration values across all loads (approximately 0.1019 to 0.1076 m/s^2) indicate that the vessel's motion characteristics are a significant factor influencing the forces, and the lashing system is designed to accommodate these general accelerations. The lashing tensions employed, utilizing 50% (12500 N) for the majority of loads and 75% (18750 N) for loads 1, 2, 3, and 7, demonstrate a planned safety margin, with the lower utilization providing a more conservative approach for most cargo. The use of two belts for the high-force loads further reinforces the safety measures implemented.

The accompanying certificate for the cargo lashing belt, with its lashing capacity of 2500 daN (equivalent to 25000 N) and a next due date of June 30, 2025, confirms the fitness and regular inspection of a crucial piece of securing equipment. The visual evidence of these belts securing cargo on deck, anchored to the vessel's lashing points, provides a tangible link to the calculated tensions and the practical implementation of the sea-fastening plan. Ultimately, the integration of this robust methodology, guided by theoretical understanding and informed by these critical calculated forces and applied tensions using certified equipment, is paramount for mitigating the risks associated with maritime cargo transport and ensuring the safety of the vessel, its crew, and the cargo.

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