SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmujournal.com.my/index.php/aram/index
ISSN: 2289-7895

Uncomplicated Evaluation of Vehicle Tie-Downs Safety Factor on Ro-Ro Ferry Affected by Lateral and Vertical Acceleration Forces from Beam Sea

Alamsyah[1,3,*], Suardi[1,3], Aqshal Dwi Rahmat[1], Nurbaya[1], Wira Setiawan[1,5], Mohammad Alifyan Hakiki[1], Riza Abdillah[1], Muhammad Uswah Pawara[1,3], Hariyono[1], Daeng Paroka[2], Andi Ardianti[4], Andi Dirga Noegraha[6]

1 Department of Naval Architecture, Institut Teknologi Kalimantan, Balikpapan 76127, Indonesia
2 Department of Ocean Engineering, Engineering Faculty, Hasanuddin University, Gowa 92171, Indonesia
3 Center of Maritime Infrastructure Engineering, Institut Teknologi Kalimantan, Balikpapan, 76127, Indonesia
4 Department of Naval Architecture, Engineering Faculty, Hasanuddin University, Gowa 92171, Indonesia
5 Marine Technology, School of Engineering, Newcastle University, Newcastle upon Tyne NE1 7RU, United Kingdom
6 Akademi Maritim Indonesia AIPI, Makassar 90211, Indonesia

ARTICLE INFO

Article history:
Received 20 March 2025
Received in revised form 23 April 2025
Accepted 30 April 2025
Available online 30 May 2025

Keywords:
Ferry ro-ro; lashing system; vertical acceleration; lateral acceleration; tie-downs; safety factor

ABSTRACT

One of the most significant forms of maritime transportation for tying together islands and coastal regions is ro-ro ferrying. Regarding the security of the cars being transported, Ro-Ro Ferry also confronts significant difficulties. incidents where the vehicle's ability to secure itself was compromised by forces of vertical and lateral acceleration when the beam sea was present. Researching an efficient vehicle fastening method is required to raise the ro-ro ferry's level of safety. To increase the safety of the ro-ro ferry, this study intends to carry out a preliminary evaluation and make recommendations about the quantity and kind of tie-downs in the lashing system. The FEM method—that is, the Ansys workbench—is employed in this investigation. For every kind of vehicle, the tie-downs is simulated to withstand stresses brought on by lateral and vertical acceleration forces. A number of lashing system angles are examined. According to the study's findings, the Truck 11 type vehicle's maximum equivalent stress when working on a 45-degree tie-downs is 36.08 MPa, while the Innova 2 vehicle's minimum equivalent stress is 13.59 MPa. When working on a tie-downs at a 70-degree angle, the highest equivalent stress for a Truck 11 vehicle is 47.95 MPa, while the minimum stress for an Innova 2 vehicle is 18.07 MPa. The tie-downs safety factor values in the lashing system range between 3.54 and 19. Because safety factor ≥ 3.5, it is the value is worth using. This is true for binding angles and all vehicle kinds.

1. Introduction

Shipping accidents in 2021 were mostly caused by human factors. In fact, there was a significant increase from the previous year of 179.55% [1]. The following year, it decreased by 31.58% where

* *Corresponding author.*
E-mail address: alamsyah@lecturer.itk.ac.id

https://doi.org/10.37934/aram.137.1.109121

ships sank and burned, becoming the most frequent shipping accidents [2]. The type of ship that was the object of the accident, according to the KNKT, was dominated by passenger ships [4]. The Indonesian Minister of Transportation Regulation defines a passenger ship as a ship carrying more than 12 (twelve) passengers [5]. Ro-ro ferries are a type of passenger ship used to carry passengers, vehicles, goods (in trucks and sometimes unpowered shipping containers) and even train cars. Handling the type of cargo on ro-ro ferries is different because it is related to the distribution of the load on the ship, which has implications for the stability of the ship, the strength of the ship and the safety of the ship. Ferry accidents in Indonesia occur not once or twice, but more than that [3]. Ferries built domestically have a large width and draft ratio, which implies that the maximum stability arm occurs at a pitch angle of less than 25 degrees [6]. According to the IMO, ships with a large width-to-draft ratio tend not to meet one of the stability criteria [7]. Ferry research has been widely conducted, covering stability, construction strength and manoeuvring, the direction of which is how ferry safety is ensured. Hasbullah *et al.*, [8] studied the influence of the operational environment on ferry manoeuvring characteristics. The response of ferry structures to internal and external loads was carried out [9-13]. In addition, research on structural fatigue on ro-ro ferries was also conducted [14-16]. Likewise, efforts are made to reduce the resistance of the ship's hull [17]. The event of a vehicle shifting or rolling over to the side of a ro-ro ferry has a large role in creating an initial tilt and immediately causing the ship to lose stability so that it sinks [18]. This condition is prone to occur during poor sailing weather conditions [19]. The government has issued regulations on the vehicle fastening system on ships [20,21]. The regulation regulates the procedures for fastening types of vehicles while sailing, but its implementation has not been effective on short routes. Therefore, it is necessary to study the potential for vehicle shifting on ro-ro ferries, the configuration of the vehicle fastening design system on ro-ro ferries and its effect on ship safety during sailing.

However, its application in the field is less effective on short tracks. On the other hand, the effectiveness of the binding system is highly dependent on the forces and moments acting on the vehicle. Therefore, vehicles that have been tied can also shift or roll over due to an ineffective binding system or binding strength that is unable to withstand the forces and moments that occur. This is the basis for studying the potential for vehicle shifting or rolling over and the design of the optimum vehicle binding configuration to minimize shifting and rolling events. The transverse shift of objects depends on their geometry and centre of gravity relative to the baseline [22,23]. Likewise with the type of vehicle and each geometric size that will be transported by the ro-ro ferry. Previous studies have studied ferry safety based on differences in weight distribution on the vehicle deck [24,25]. Experimental methods are used without considering the potential for vehicle shifting and rolling over. This study will produce lateral and vertical acceleration values for vehicles due to the influence of beam sea. The output of lateral and vertical vehicle forces will be used as a reference in conducting initial assessments and proposing tie-downs fastener sizes and materials on the lashing system to improve the safety of ro-ro ferries. This study focuses on the strength of vehicle binding materials reviewed based on their safety factor value. Several previous studies that have been conducted in relation to the possibility of vehicle shifting or overturning on ro-ro ferries include the analysis of lateral acceleration due to ship motion as a function of position on the ship [26] and testing a model to predict lateral acceleration based on the IMO second generation stability criteria [27]. The same thing was done by Alamsyah *et al.,* [28,29] by predicting the lateral and vertical acceleration of vehicles based on their position on the car deck using the strip theory method under the influence of side waves. As a continuation of this study, the effect of ship motion on the vehicle binding system on ro-ro ferries will be analysed, which will then be used to design the size and material of the vehicle binding so that accidents due to vehicle shifting or overturning can be minimized in the future. The estimation of transverse and vertical forces due to the rolling motion of side waves is calculated.

Based on the results of the motion simulation in the previous stage, the analysis of vehicle shifting and overturning is carried out using the principle of force balance and geometric characteristics of the vehicle, such as the width of contact with the deck and the height of the centre of gravity on the deck [30].

2. Methodology

2.1 Ferry Ro-Ro

A ferry is a means of transportation that is widely used as a means of crossing between islands and can transport passengers, vehicles and goods from one island to another. Ro-Ro is an abbreviation for roll-on, roll-off. A ro-ro ship is a ship used to carry cargo that has wheels. Vehicles on the ship are loaded and unloaded through the ramp door. The ramp door functions as a bridge connecting the ship to the dock so that loaded vehicles can enter and exit easily. The ramp door is located at the bow and stern.

In this study, data will be taken from vehicles transported by ro-ro ferry ships on three (three) crossing routes. The vehicle data taken is the type of four (four) wheeled vehicles or more with specifications of length, width, height, distance between vehicles, long post (measured from the afterpeak of the ship to the centre of gravity of the vehicle), offset (measured from the centreline of the ship to the centre of gravity of the vehicle) and height (measured from the base to the centre of gravity of the vehicle).

2.2 Ship Motion

In designing a ship, one of the factors that must be considered is the various strengths of water currents. Seakeeping is defined as the movement of a ship influenced by external forces caused by water conditions. A ship moving in the open sea always experiences movement, namely three translational movements, including surging, swaying and heaving movements. And three rotational movements, including rolling, pitching and yawing movements. The various movements of the ship according to its axis as shown in Figure 1 below.

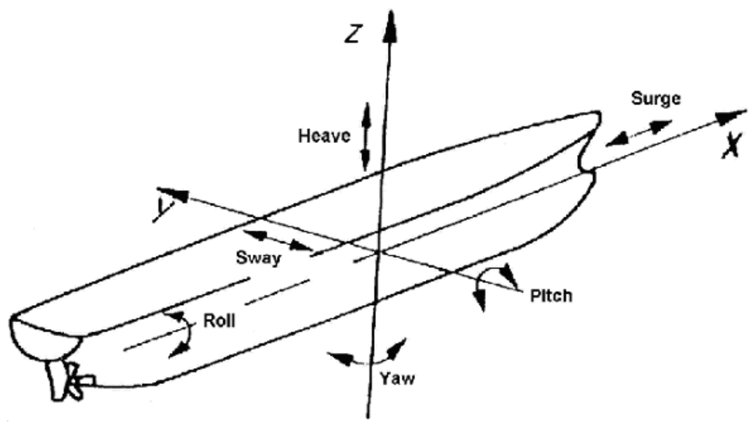


Fig. 1. The six degrees of freedom

2.3 Lateral and Vertical Acceleration

Lateral acceleration is the acceleration imparted to an object in a direction perpendicular to its direction of motion. Lateral acceleration refers to the change in velocity in the lateral or horizontal direction. This can be caused by factors such as rotation, turning or sideways motion. Lateral acceleration can be measured in meters per second squared (m/s²) and is commonly expressed as the centrifugal acceleration felt by passengers or objects in the vehicle. Vertical acceleration, on the other hand, is the acceleration imparted to an object in a vertical direction or perpendicular to the surface of the earth. Vertical acceleration refers to the change in velocity in the vertical or up-and-down direction of the object. This can be caused by factors such as ocean waves, shocks or up-and-down motion. Vertical acceleration is also measured in meters per second squared (m/s²).

2.4 Stowage Plan

The vehicle deck of a ferry is a special place for vehicles. In the vehicle deck, it is necessary to arrange the cars so that the space can be used optimally. With a narrow room shape, cars should be parked in a parallel shape. In addition to saving space, parking aims to speed up the loading and unloading process of vehicles. Parking is done in two ways, namely parallel parking and angled parking, but the most dominant is the parallel parking system as show in Figure 2 below.

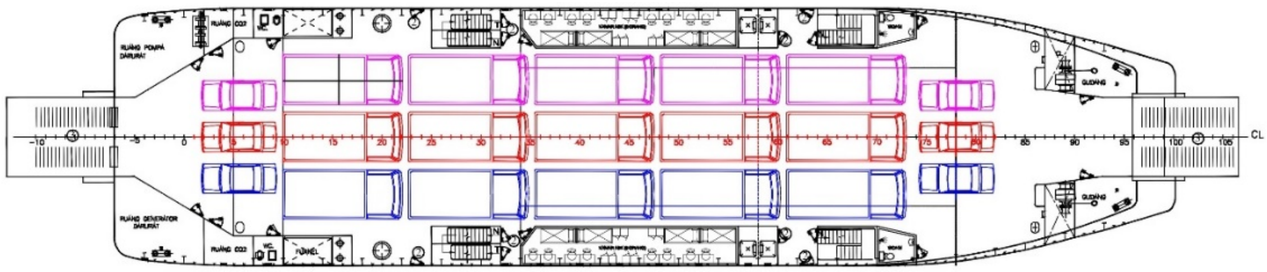


Fig. 2. Stowage plan

2.5 The Equivalent Stress or Von Misses Stress

Equivalent stress, commonly called von Mises stress, produced by Finite Element analysis is a combination of normal stress and shear stress. The Eq. (1) used is as follows [31]:

$$\sigma_v = \sqrt{\sigma^2 + 3\tau^2} \tag{1}$$

where σ = normal stress [MPa]; τ = shear stress [MPa]; σ_v = Equivalent stress [MPa].

2.6 The Safety Factor

Calculating the safety factor for construction. Since the safety factor is a quantitative comparison between the material yield stress and the maximum working stress that occurs during construction, its value must be greater than 1 (safety factor > 1). The maximal working stress in a safe environment shouldn't be higher than the yield stress. The following Eq. (2) can be used to get the safety factor value:

$$S_f = \frac{\sigma_{yield}}{\sigma_v} \tag{2}$$

where *sf* = safety factor [>1]; σ_{yield} = yield stress of material [MPa]; σ_v= maximum equivalent stress acting on a construction after being subjected to force [MPa].

2.7 Finite Element Method

The finite element method combines several mathematical concepts to produce linear or nonlinear system equations. The number of equations produced is usually very large, reaching more than 20,000 equations. Therefore, this method has little practical value if it does not use an adequate computer. Advances in computer software have been able to facilitate the solution of engineering problems on a large scale. Likewise in the field of structural analysis, which uses the finite element method as a basis for accurate and easy-to-operate solutions. The finite element method is a method for solving engineering problems that uses an approach that involves dividing (discretizing) the object to be analysed into the form of finite elements that are interrelated with each other. Engineering problems are usually approached with a mathematical model in the form of differential equations. Each mathematical model has other mathematical equations that are determined based on assumptions and actual conditions called boundary conditions.

3. Results

3.1 Stowage Plan Ferry Ro-Ro

The observation data is then made into a car deck with AutoCAD software. A car deck is a ship deck that functions as a place-to-place cargo in the form of vehicles. The data obtained will be used as coordinate points in the analysis, where modelling is carried out in the Maxsurf software to determine the weight distribution on the car deck and the position of each vehicle. The Balikpapan-Penajam Paser Utara ro-ro ferry route is the case study for this research. The following are the car decks on each crossing route as Figure 3.

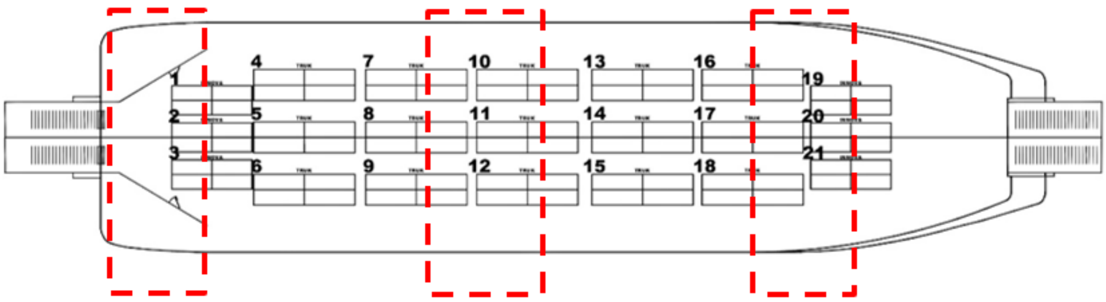


Fig. 3. Stowage plan of ferry ro-ro Balikpapan – Penajam Paser Utara route

3.2 Lateral and Vertical Acceleration Analysis Including Resultant Forces

The heave value is 0.740 m; the pitch value is 1.460 deg; and the roll value is 14.390 deg. The Response Amplitude Operator (RAO) graph at 0 knots with a wave arrival angle of 90° (beam sea) can as shown in Figure 4 below.

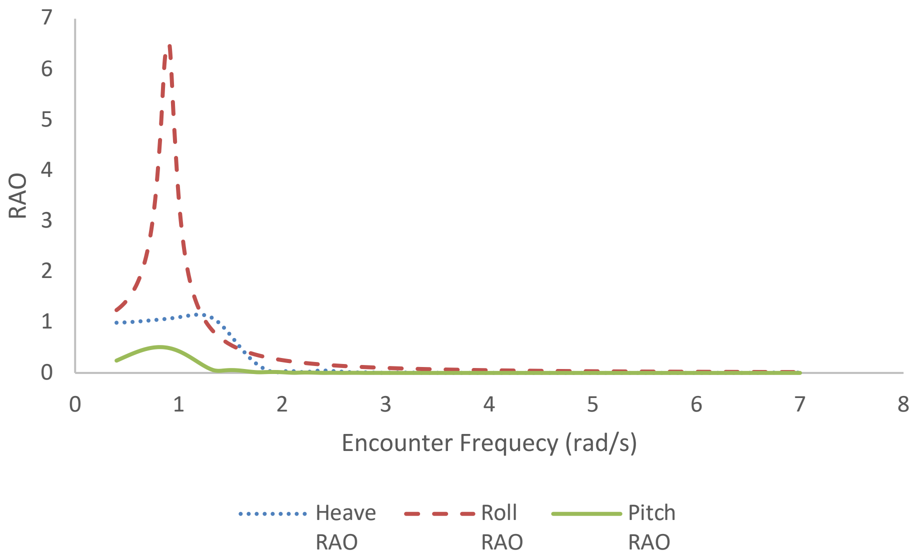


Fig. 4. RAO on 0 knot, 90° (Beam Sea)

Figure 4 explains that the RAO at a ship speed of 0 knots with a wave arrival angle of 90° (beam sea) on the heave and pitch ship movements is shown to have increased at an encounter frequency of 0.4 rad/s because at this encounter frequency the ship's response gives a surge effect that can be felt so that the RAO value at an encounter frequency of 0.4 rad/s increases. After obtaining the RAO value, analyse the acceleration values laterally and vertically with variations in wave height. In this study, only a few samples were taken as representatives of each vehicle position that had a significant effect when receiving waves from the side, namely the rear, middle and front of the ship on the portside (left of the ship), centre (middle of the ship) and starboard (right of the ship). The lateral and vertical acceleration values of each vehicle sample at each wave variation as shown in Figure 5 to Figure 10 below.

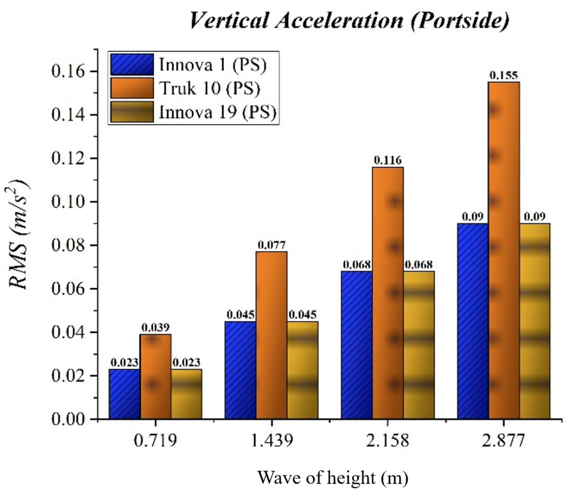


Fig. 5. Vertical acceleration of the car deck at portside position

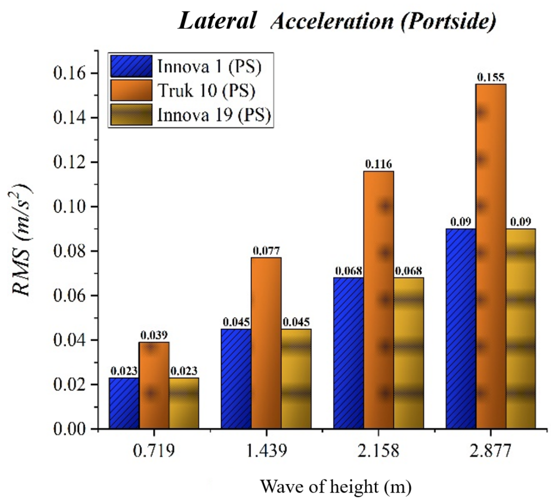


Fig. 6. Lateral acceleration of the car deck at portside position

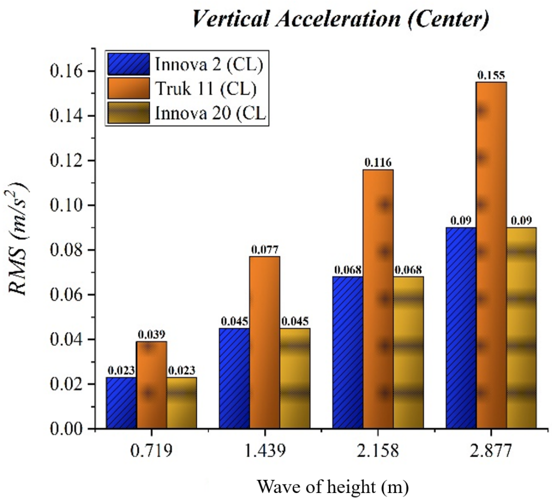


Fig. 7. Vertical acceleration of the car deck at starboard side position

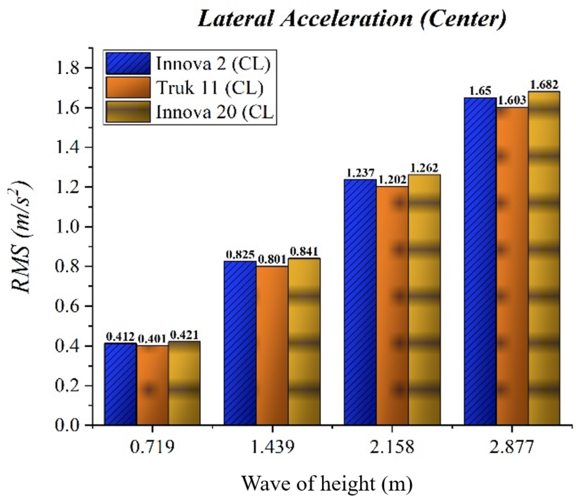


Fig. 8. Lateral acceleration of the car deck at starboard position

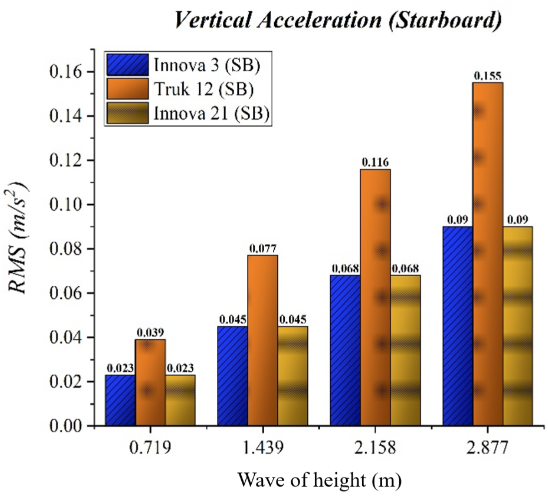


Fig. 9. Vertical acceleration of the car deck at centre side position

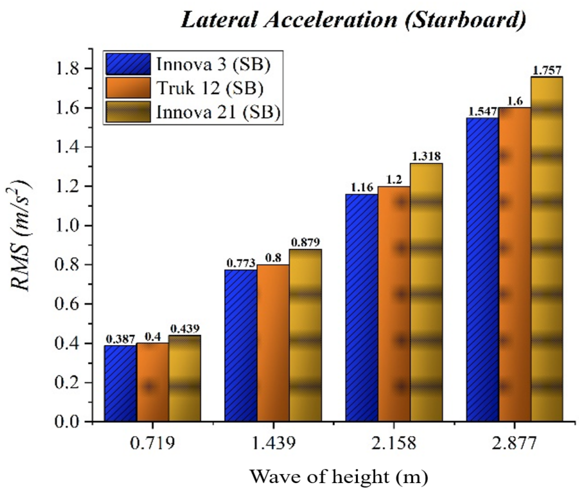


Fig. 10. Lateral acceleration of the car deck at centre position

After obtaining the vertical and lateral acceleration values based on the type and position of the vehicle, the next step is to determine the potential vertical and lateral force values. The Freebody diagram for calculating the force is shown in Figure 11.

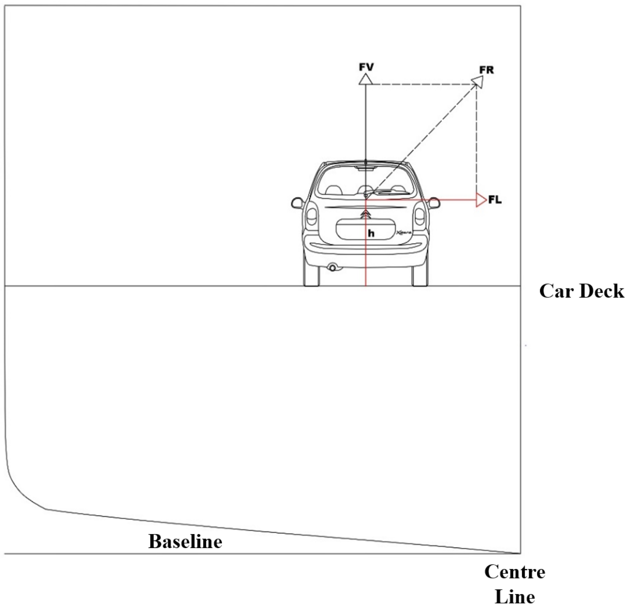


Fig. 11. Freebody diagram of vertical & lateral force of the vehicle

Table 1
The vehicle variable of the Balikpapan-Penajam Paser Utara route

Item	Massa (kg)	$h_{lateral}$ (m)	$h_{vertical}$ (m)	$a_{lateral}$ (m/s^2)	$a_{vertical}$ (m/s^2)
Innova 1 (PS)	1690	2.100	0.880	1.707	0.090
Truck 10 (PS)	4300	2.960	1.125	1.508	0.155
Innova 19 (PS)	1690	2.100	0.880	1.541	0.090
Innova 2 (CL)	1690	0.000	0.880	1.650	0.090
Truck 11 (CL)	4300	0.000	1.125	1.603	0.155
Innova 20 (CL)	1690	0.000	0.880	1.682	0.090
Innova 3 (SB)	1690	2.100	0.880	1.547	0.090
Truck 12 (SB)	4300	2.960	1.125	1.600	0.155
Innova 21 (SB)	1690	2.100	0.880	1.757	0.090

Table 2
The vehicle variable of the Balikpapan-Penajam Paser Utara route

Item	$h_{vertical}$ *(m)*	Inertia *(kg.m^2)*	f_{gesek} *(N)*	FR *(N)*
		1/2mR^2	$\mu_s .N$	$\sqrt{F_L^2 + F_V^2}$
Innova 1 (PS)	0.880	104	9937	2889
Truck 10 (PS)	1.125	538	25284	6519
Innova 19 (PS)	0.880	104	9937	2609
Innova 2 (CL)	0.880	104	9937	2793
Truck 11 (CL)	1.125	538	25284	6925
Innova 20 (CL)	0.880	104	9937	2847
Innova 3 (SB)	0.880	104	9937	2619
Truck 12 (SB)	1.125	538	25284	6912
Innova 21 (SB)	0.880	104	9937	2973

3.3 Determination of Materials and Dimensions of Fasteners and Modelling using FEM

In this study, the material used for lashing system is stainless steel type 340L with 6 x 7-strand wire rope, which has the physical properties shown in Table 3 and Figure 12.

Table 3
The mechanical properties of wire rope

Particular	value	units
E - Modulus	220	Gpa
Ultimate stress	485	*Mpa*
Yield	170	*Mpa*
Density	7.93	g/m^3

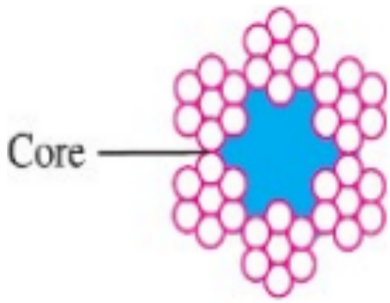
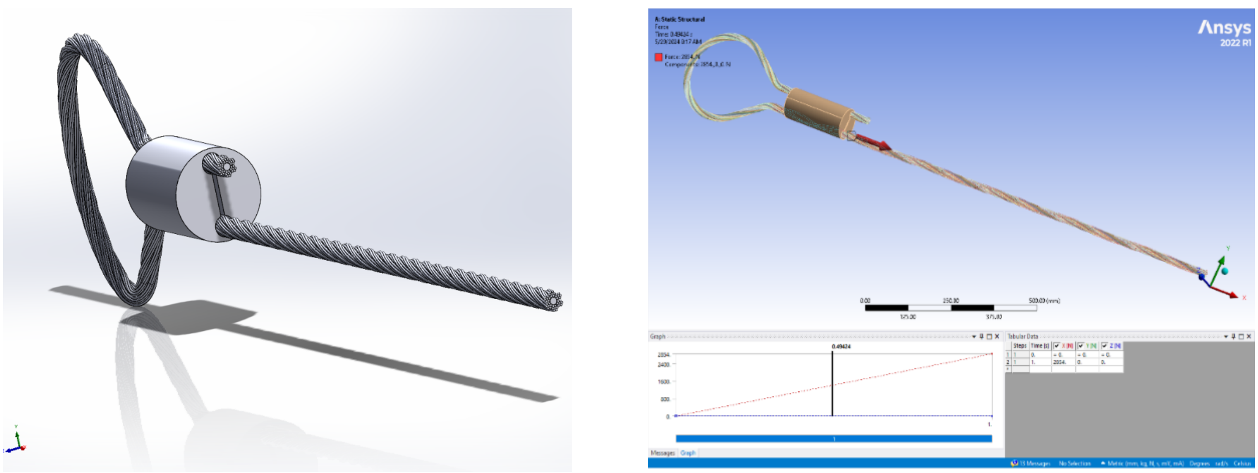


Fig. 12. Wire rope 6x7

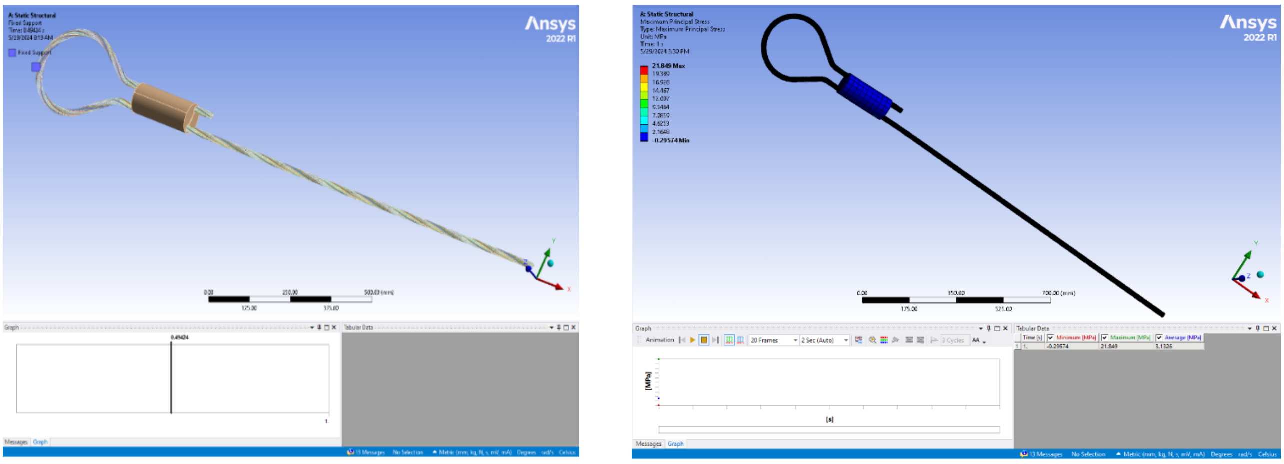
Lashing system modelling is done with the help of SolidWorks software. Lashing system modelling is done in 3D and analysed using FEM. In this study, we used angle variations of 40 and 75 degrees to determine the maximum stress and deformation of the angle shown in Table 4 and Figure 13.

Table 4
Basic of the resultant force, at 45° and 70°

Item	$F_{Resultante}$ (N)	Force at 45° (N)	Force at 70° (N)
	m.a	*m.a*	*m.a*
Innova 1 (PS)	2889	2043	2715
Truck 10 (PS)	6519	4610	6126
Innova 19 (PS)	2609	1845	2452
Innova 2 (CL)	2793	1975	2625
Truck 11 (CL)	6925	4897	6507
Innova 20 (CL)	2845	2012	2673
Innova 3 (SB)	2619	1852	2461
Truck 12 (SB)	6912	4887	6495
Innova 21 (SB)	2973	2102	2794



(a) (b)



(c) (d)

Fig. 13. Scheme of FEM analysis (a) 3D model (b) boundary condition of force (c) boundary condition of displacement (d) analysis

Boundary conditions are applied to the FEM simulation specifically on the wire rope in the form of normal forces that have been calculated manually based on the rope inclination angle approach. Furthermore, it is input into the 3D wire rope model. The model is also given a fixed support at one end of the wire rope to approach the actual event. The mesh size used is 2 mm based on the literacy of the software.

The following is a recapitulation of the maximum stress values for each type. Recapitulation of the analysis of the maximum stress values and minimum stress values with variations of angles of 45 and 70 degrees for each type of vehicle.

Table 5
Recapitulation of stress at wire rope at 45°

Vehicle	Force (N)	Minimum Stress (*MPa*)	Maximum stress (*MPa*)
Innova 1	2043	-0.21	15.05
Truck 10	4610	-0.49	33.97
Innova 19	1845	-0.19	13.59
Innova 2	1975	-0.21	14.55
Truck 11	4897	-0.52	36.08
Innova 20	2012	-0.19	14.82
Innova 3	1852	-0.53	13.64
Truck 12	4887	-0.52	36.01
Innova 21	2102	-0.22	15.49

Table 6
Recapitulation of stress at wire rope at 70°

Vehicle	Force (N)	Minimum Stress (*MPa*)	Maximum stress (*MPa*)
Innova 1	2715	-0.28	20.00
Truck 10	6126	-0.53	45.14
Innova 19	2452	-0.26	18.07
Innova 2	2625	-0.27	19.34
Truck 11	6507	-0.69	47.95
Innova 20	2673	-0.28	19.69
Innova 3	2461	-0.26	18.13
Truck 12	6495	-0.69	47.86
Innova 21	2794	-0.29	20.59

3.4 Safety Factor

Table 7 and Table 8 present the equivalent stress values produced by the FEM simulation reaction action. The lashing system angle consistently has implications for the equivalent stress value on the wire rope. For the lashing system, the 70° angle produces a higher stress and for the 45° angle lashing system, it is relatively lower. This applies to all types of vehicles tied to the car deck of the ro-ro ferry. The context in the field sometimes uses a lashing system angle that is larger than the experimental simulation used in the study. This can have implications for increasing the equivalent stress value of the wire rope.

Table 7
Recapitulation of safety factor at wire rope at 45°

Vehicle	Maximum stress at 45° (*MPa*)	Ultimate stress of material (*MPa*)	Yield stress of material (*MPa*)	*Safety factor*	noted
Innova 1	15.05	485	170	11.29	eligible
Truck 10	33.97			5.00	eligible
Innova 19	13.59			12.50	eligible
Innova 2	14.55			11.68	eligible
Truck 11	36.08			4.71	eligible
Innova 20	14.82			11.46	eligible
Innova 3	13.64			12.46	eligible
Truck 12	36.01			4.72	eligible
Innova 21	15.49			10.97	eligible

Table 8
Recapitulation of safety factor at wire rope at 70°

Vehicle	Maximum stress at 70° (*MPa*)	Ultimate stress of material (*MPa*)	Yield stress of material (*MPa*)	*Safety factor*	noted
Innova 1	20.00	485	170	8.50	eligible
Truck 10	45.14			3.77	eligible
Innova 19	18.07			9.41	eligible
Innova 2	19.34			8.79	eligible
Truck 11	47.95			3.54	eligible
Innova 20	19.69			8.63	eligible
Innova 3	18.13			9.37	eligible
Truck 12	47.86			3.55	eligible
Innova 21	20.59			8.26	eligible

A high equivalent stress value will have implications for the safety factor of the wire rope binding material. The calculation of the safety factor of the wire rope that is the lashing system material can be done by comparing the equivalent stress value and the yield stress value of the material using Eq. (2). Wire rope safety factor is considered according to the guidelines for the classification and construction Volume I: Guidelines for certification of lifting appliances. The value used for wire rope safety factor is a minimum of 3.5 [32]. So, it can be said that the status of the lashing system is safe for use on several vehicles. Although the research results show safe conditions for the lashing system, these findings also recommend not using a lashing system angle greater than 70° because it has been proven to increase the equivalent stress value and reduce the safety factor

4. Conclusions

The maximum lashing system stress value at an angle of 45° with the type of vehicle Innova 2 is 15.05 MPa, Truck 10 is 33.97 MPa, Innova 19 is 13.59 MPa, Innova 2 is 14.55 MPa, Truck 11 is 36.08 MPa, Innova 20 is 14.82 MPa, Innova 3 is 13.64 MPa, Truck 12 is 36.01 MPa and Innova 21 is 15.49 MPa. The maximum stress value of lashing system at an angle of 70° with the type of vehicle Innova 2 is 20.00 MPa, Truck 10 is 45.14 MPa, Innova 19 is 18.07 MPa, Innova 2 is 19.34 MPa, Truck 11 is 47.95 MPa, Innova 20 is 19.69 MPa, Innova 3 is 18.13 MPa, Truck 12 is 47.86 MPa and Innova 21 is 20.59 MPa. For the safety factor value resulting from the comparison of the material yield stress to the maximum stress of the simulation, it states that the lashing system for several types of vehicles used is safe to use on vehicles. The vehicle with the vehicle with the largest safety factor value is the Innova 19, with a value of 12.50 at an angle of 45° and 9.41 at an angle of 70°. Meanwhile, the truck type 11 has the truck type 11 has the smallest safety factor value at a 45° angle, with a safety factor value of 4.71 at a 45° angle and 3.54 at a 70° angle.

Acknowledgement
This research was funded by a grant from Ministry of Education, Culture, Research and Technology of Indonesia (037/E5/PG.02.00.PL./2024 and 6465/IT10.II/PPM.04/2024)

References
[1] Sadya S. “Ada 19 Kecelakaan Pelayaran di Indonesia pada 2021.” *DataIndonesia.id*, editor. (2022).
[2] Mustajab R. “Terdapat 13 Kecelakaan Pelayaran di Indonesia pada 2022.” *DataIndonesia.id*, (2023).
[3] Komite Nasional Keselamatan Transportasi. “Laporan Statistik Investigasi Kecelakaan Transportasi 2022 Semester 1. Jakarta; 2022.” (2022).
[4] Hasugian, Sereati, AA Istri Sri Wahyuni, Maulidiah Rahmawati and Arleiny Arleiny. "Pemetaan Karakteristik Kecelakaan Kapal di Perairan Indonesia Berdasarkan Investigasi KNKT." *Warta Penelitian Perhubungan* 29, no. 2 (2018): 229-240. https://doi.org/10.25104/warlit.v29i2.521
[5] Kementrian Perhubungan Republik Indonesia. “Peraturan Menteri Perhubungan Republik Indonesia Nomor PM 26 Tahun 2022 Tentang Pengawakan Kapal Niaga.” (2022).
[6] Paroka, Daeng. "Karakteristik geometri dan pengaruhnya terhadap stabilitas kapal ferry ro-ro Indonesia." *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan* 15, no. 1 (2018): 1-8. https://doi.org/10.14710/kpl.v15i1.17272
[7] IMO, S. "International code on intact stability." (2008).
[8] Hasbullah, Mansyur, Daeng Paroka and Hanisa Hanisa. "The Effect of Waves on the Maneuvering Characteristics of Ferry Vessel." *Jurnal Penelitian Enjiniring* 21, no. 1 (2017): 11-22. https://doi.org/10.25042/jpe.052017.02
[9] Wulandari, Amalia Ika. "Analisis Pengaruh Jarak Gading Terhadap Kekuatann Memanjang Kapal Ferry Ro-Ro 5000 GT." *JTT (Jurnal Teknologi Terpadu)* 8, no. 2 (2020): 101-105.
[10] Falevi, Ahmed Reza, Amalia Ika Wulandari, Muhammad Uswah Pawara, Wira Setiawan and Andi Mursyid Nugraha Arifuddin. "Investigating the Local Stress of Car Deck Ro-Ro 5000 GT." *EPI International Journal of Engineering* 4, no. 1 (2021): 51-56. https://doi.org/10.25042/epi-ije.022021.08
[11] Alamsyah, Alamsyah, Septiany Tri Pangestu and Amalia Ika Wulandari. "Respon struktur akibat perubahan jarak stiffener pada car deck Kapal Ferry Ro-Ro." *Turbo: Jurnal Program Studi Teknik Mesin* 10, no. 2 (2021). https://doi.org/10.24127/trb.v10i2.1705
[12] Alamsyah, Alamsyah, Amalia Ika Wulandari, Muhammad Uswah Pawara and Muhammad Yusuf Al-Hafidz. "Analisis kekuatan struktur ramp door haluan pada kapal Ferry Ro-Ro 1500 GT dengan variasi beban menggunakan Finite Element Method." *Turbo: Jurnal Program Studi Teknik Mesin* 11, no. 2 (2022). https://doi.org/10.24127/trb.v11i2.2161
[13] Pawara, M. Uswah, Alamsyah Alamsyah, Rodlian Jamal Ikhwani, Ade Ray Siahaan and Andi Mursyid Nugraha Arifuddin. "A Finite Element Analysis of Structural Strength of Ferry Ro-Ro’s Car Deck." *INVOTEK: Jurnal Inovasi Vokasional dan Teknologi* 22, no. 1 (2022): 47-60. https://doi.org/10.24036/invotek.v22i1.959
[14] Alam, Alamsyah, A. B. Mapangandro and M. U. Pawara. "Fatigue Life Analysis of Ramp Door Ferry Ro-Ro Gt 1500 Using Finite Element Method." *Majalah Ilmiah Pengkajian Industri; Journal of Industrial Research and Innovation* 15, no. 1 (2021): 42-49. https://doi.org/10.29122/mipi.v15i1.4744

[15] Alamsyah, Alamsyah, Samsu Dlukha Nurcholik, Suardi Suardi, M. U. Pawarah and Jumalia Jumalia. "The strength and fatigue life analysis of sedan car ramp of the ferry Ro-Ro 5000 GT using finite element method." *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan* 18, no. 2 (2021): 101-110. https://doi.org/10.14710/kapal.v18i2.37518
[16] Wulandari, Amalia Ika, Luh Putri Adnyani and Rodlian Jamal Ikhwani. "Fatigue Analysis of 5000 GT Ferry Ro-Ro's Car Deck Using Finite Element Method." *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan* 18, no. 3 (2021): 160-170. https://doi.org/10.14710/kapal.v18i3.39268
[17] Putranto, Vicky Adrian, Allessandro Utomo and Gunawan. "Interaction Analysis of Micro Bubbles in the Flat Plate to Reduce Drag using Computational Fluid Dynamic." *Semarak Engineering Journal 4, no. 1* (2024): 18-28.
[18] Komite Nasional Keselamatan Transportasi. "Investigasi Kecelakaan Pelayaran: Tenggelamnya KMP. Munawar Ferry Perairan Selat Alas, 4 Nautical Mile Timur Pelabuhan Kayangan Lombok Timur, Nusa Tenggara Barat. Jakarta; (2014).
[19] balitribun. "Gelombang Tinggi Hantam Selat Lombok, KMP Primera Oleng, Truk Tronton Terguling." (2019).
[20] Kemenko Bidang Kemaritiman dan Investasi. "Peraturan Menteri Perhubungan Republlk Indonesia Nomor PM 30 Tahun 2016 Tentang Kewajiban Pengikatan Kendaraan Pada Kapal Angkutan Penyeberangan." (2016).
[21] Badan Pemeriksa Keuangan Indonesia. "Peraturan Menteri Perhubungan Republik Indonesia Nomor PM 115 Tahun 2016 Tentang Tata Cara Pengangkutan Kendaraan Di Atas Kapal." (2016).
[22] Crossland, P. and K. J. N. C. Rich. "A method for deriving MII criteria." In *Conference on Human Factors in Ship Design and Operation, London, UK*. 2000.
[23] Alamsyah, Alamsyah, Zen Zulkarnaen and Suardi Suardi. "The Stability Analyze of KM. Rejeki Baru Kharisma of Tarakan–Tanjung Selor Route." *TEKNIK* 42, no. 1: 52-62. https://doi.org/10.14710/teknik.v42i1.31283
[24] Paroka, Daeng andi Haris Muhammad and Sabaruddin Rahman. "Hydrodynamics factors correspond to the weather criterion applied to an Indonesian Ro-Ro Ferry with different weight distributions." *International Journal of Technology* 12, no. 1 (2021): 126-138. https://doi.org/10.14716/ijtech.v12i1.4246
[25] Paroka, Daeng andi Haris Muhammad and Sabaruddin Rahman. "Safety of an Indonesian ro-ro ferry with different weight distribution on vehicle deck." In *AIP Conference Proceedings*, vol. 2543, no. 1. AIP Publishing, 2022. https://doi.org/10.1063/5.0094745
[26] Paroka, D., A. H. Muhammad, S. Rahman and Fuad Mahfud Assidiq. "Vulnerability of Ship with a Large Breadth to Draught Ratio Against Excessive Acceleration Criteria." In *IOP Conference Series: Earth and Environmental Science*, vol. 1166, no. 1, p. 012008. IOP Publishing, 2023. https://doi.org/10.1088/1755-1315/1166/1/012008
[27] Paroka, Daeng andi Haris Muhammad and Sabaruddin Rachman. "Vulnerability Assessment for Excessive Acceleration Failure Mode of an Indonesian Ro-Ro Ferry by Model Experiment." *International Journal of Technology* 16, no. 1 (2025). https://doi.org/10.14716/ijtech.v16i1.6315
[28] Alamsyah, W. Setiawan, Daeng Paroka, N. Nurbaya, H. S. Sitanggang and M. R. F. Jaya. "Characteristics of Lateral Acceleration and Vertical Acceleration of the Position of the Vehicle on the Ferry Ro-Ro Car Deck." *International Journal of Marine Engineering Innovation and Research* 8, no. 3 (2023): 530-534. https://doi.org/10.12962/j25481479.v8i3.18792
[29] Setiawan, Wira, M. Uswah Pawara, Daeng Paroka and Andi Ardianti. "An Estimation Method for the Overthrowing Moment of Vehicles on the Car Deck of the Ro-Ro Ferry." *Engineering, Technology & Applied Science Research* 15, no. 1 (2025): 19303-19309. https://doi.org/10.48084/etasr.8887
[30] Crossland, P. and K. J. N. C. Rich. "Validating a model of the effects of ship motion on postural stability." In *International Conference of Environmental Ergonomics*, vol. 77, pp. 385-388. 1998.
[31] Biro Klasifikasi Indonesia. "Rules for Classification and Construction, Part 1 Seagoing Ships, Rules For Hull, Volume II January 2025 Edition." (2025).
[32] Biro Klasifikasi Indonesia. "The guidelines for the classification and construction, Part 7 Class Notation, Volume I: Guidelines for certification of lifting appliances, 2013 edition." (2013).