



## Seakeeping Performance and Passenger Comfort Assessment of a 300 GT Ro-Ro Ferry Using RAO, MSI, and MII Analyses

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### Abstract

This study investigates the motion responses and onboard comfort of a 300 GT roll-on/roll-off (Ro-Ro) ferry subjected to varying wave directions and operating speeds. The assessment was conducted using Response Amplitude Operator (RAO), Motion Sickness Incidence (MSI), and Motion-Induced Interruptions (MII) as the primary evaluation parameters. Numerical simulations were carried out in Maxsurf Motion software under wave heights of 3.0 m and 3.5 m, with wave encounter angles of 0° (following seas), 90° (beam seas), and 180° (head seas) at vessel speeds of 0 and 12 knots. MSI values were obtained through both simulation and analytical methods, while MII was evaluated based on ISO 2631 guidelines across three onboard locations: the passenger deck, navigation bridge, and vehicle deck. The RAO analysis indicated compliance with NORDFORSK (1987) comfort limits under following and head seas, but roll responses exceeded permissible thresholds in beam seas. MSI remained within the moderate comfort zone under most conditions, except under head seas at 12 knots, where values approached the alert category. MII levels were generally acceptable, although “probable” interruption classifications emerged on the passenger and vehicle decks during beam sea conditions. The findings highlight the critical influence of wave direction and vessel speed on onboard comfort and safety, offering practical guidance for ferry design, operational planning, and mitigation strategies to enhance both passenger experience and crew efficiency in dynamic sea environments.

**Keywords:** Ro-Ro Ferry; Seakeeping; RAO; MSI; MII; Passenger Comfort

## 1. INTRODUCTION

Roll-on/roll-off (Ro-Ro) ferries are a vital part of Indonesia’s maritime transport system, supporting short- to medium-distance inter-island transport of passengers and freight [1]. However, their open vehicle decks and large windage areas make them highly susceptible to wave-induced motions, which can compromise their stability, reduce passenger comfort, and threaten operational safety [2]. Seakeeping performance, defined as a vessel’s dynamic response to pitch, roll, and heave excitations, is crucial for safe and reliable vessel operations [3].

The Response Amplitude Operator (RAO) method is widely applied to predict vessel motion responses under specific sea states, thereby assisting in the evaluation of operational limits and safety margins [6], [7]. RAO represents the frequency-dependent ratio between wave excitation and vessel response, which is strongly influenced by the hull form, displacement, loading condition, and wave heading [8] – [12]. RAO behavior is classified into subcritical, resonant, or supercritical responses depending on the encounter frequency [13]. Accordingly, RAO-based analyses have been extensively applied in hull optimization, voyage planning, and passenger comfort evaluations, particularly for RoPax-type vessels [11], [14] – [17].

Previous studies have examined RAO responses for container ships [18], barges [19], and other vessel types using numerical and data-driven approaches [20]. For Ro-Ro ferries, studies have primarily focused on heave, pitch, and roll motions [21], with IoT-based monitoring systems proposed to enhance safety [22]. The influence of vessel speed on motion characteristics has also been emphasized [6]. More recent studies have extended the RAO applications to speed loss, efficiency, and structural response, showing that beam seas (90°) induce



severe heave and roll motions, whereas catamaran vessels show reduced motions at a separation-to-length ratio of 0.4 [23].

Despite these contributions, RAO-based investigations of small Ro-Ro ferries (~300 GT) operating in Indonesian waters are limited. Furthermore, the integration of MSI and MII metrics into RAO-based seakeeping assessments has not been comprehensively addressed, even though these parameters are essential for evaluating passenger comfort and crew safety. This study addresses these gaps by combining RAO, MSI, and MII analyses to evaluate the seakeeping performance of a 300 GT Ro-Ro ferry operating in the South Kalimantan waters. Numerical simulations were conducted using Maxsurf Motion for wave headings of 0°, 90°, and 180°, with significant wave heights of 3.0 m and 3.5 m. The motion responses were assessed at the passenger deck, navigation bridge, and vehicle deck. The findings are expected to provide insights into improving vessel seakeeping, passenger comfort, and crew safety in domestic Ro-Ro ferry operations.

## 2. METHODS

### 2.1. Research Object and Treatment

The subject of this study is a 300 GT Roll-on/Roll-off (Ro-Ro) ferry operating in domestic Indonesian waters. This vessel represents a typical maritime transport mode for passengers and vehicles between the islands. The technical specifications, including the principal dimensions and general arrangement, were obtained from official documentation and are summarized in Table 1, with the layout illustrated in Figure 1.

Table 1. Technical Specification of the Ro-Ro Ferry

No	Parameter	Value	Unit
1	Length Over All (LOA)	39.36	m
2	Length Between Perpendiculars (LBP)	34.50	m
3	Beam (B)	11.00	m
4	Depth (H)	3.30	m
5	Draft (T)	2.30	m
6	Service Speeds (Vs)	12.00	knot
7	Crew capacity	16	persons
8	Passanger Capacity	180	persons

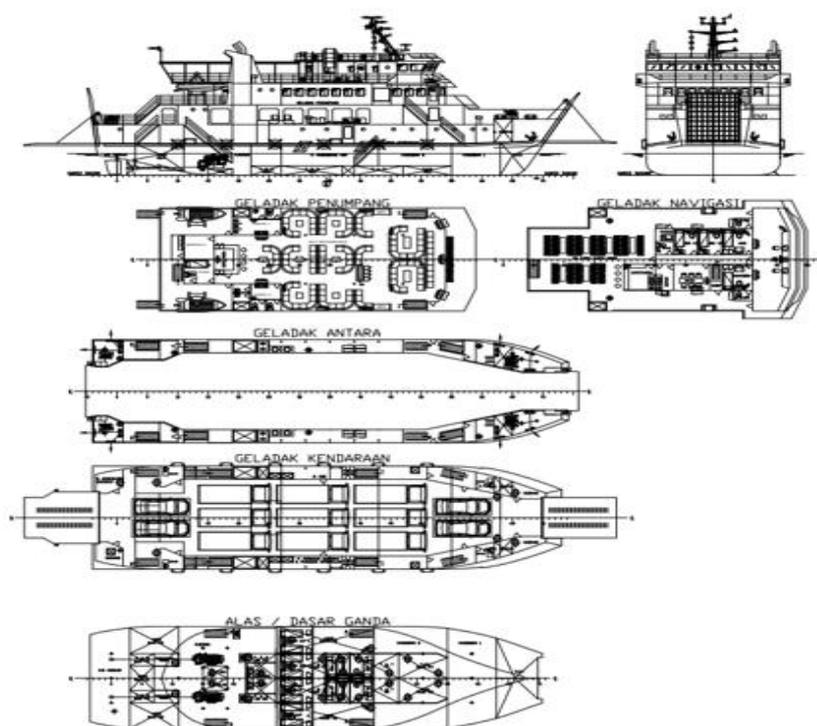


Figure 1. General Arrangement of The Ferry



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A parametric approach was applied by maintaining the hull form and principal dimensions constant while varying the operational and environmental conditions. The independent variables included wave direction (0° head seas, 90° beam seas, 180° following seas), wave height (3.0 m and 3.5 m), and ship speed (0 and 12 knots), simulating both stationery and cruising conditions to evaluate vessel motion and onboard comfort indices.

## 2.2. Research Methods and Procedures

Numerical simulations were conducted using Maxsurf Modeler and Maxsurf Motion to evaluate the seakeeping performance and passenger comfort of the 300 GT Ro-Ro ferry. The methodology consisted of the following steps.

### 1) Literature Review

Relevant studies on ship motion dynamics, seakeeping, and passenger comfort indices were examined.

### 2) Data Collection

General arrangement drawings and principal dimensions were obtained from official sources.

### 3) Hull Modeling

A 3D hull geometry was developed in Maxsurf Modeler based on CAD designs.

### 4) Seakeeping Simulation

Motion responses were simulated in Maxsurf Motion with inputs including hull geometry, displacement, loading conditions, center of gravity, mass distribution, damping factors, wave headings, wave heights, ship speeds, ocean wave spectra, water density, remote location points, and numerical settings (mesh resolution, mapping terms, time step, and simulation duration).

### 5) Response Amplitude Operator (RAO) Calculation

The RAO was computed to quantify vessel motions in heave, pitch, and roll across different frequencies and headings.

### 6) Passenger Comfort Analysis:

- Motion Sickness Incidence (MSI): Calculated from vertical acceleration data in accordance with ISO 2631-1:2020.
- Motion-Induced Interruptions (MII): Evaluated using NORDFORSK (1987) motion acceptability thresholds.

### 7) Location-Specific Assessment

The MSI and MII were analyzed on the passenger deck, navigation bridge, and vehicle deck.

### 8) Model Validation

To ensure simulation reliability, the hull model and seakeeping predictions were validated using the following:

1. RAO Comparison: Heave, pitch, and roll RAO curves of the 300 GT ferry were compared with published data for similar Ro-Ro ferries to verify the dynamic response trends.
2. Sensitivity Analysis: Key simulation parameters, including the mesh resolution, time step, and loading conditions, were varied to assess the robustness of the results.

This integrated validation confirmed that the numerical model provided reliable predictions of the ship motion, MSI, and MII under the evaluated operational and environmental conditions.

## 3. RESULTS AND DISCUSSION

This study analyzed the influence of varying wave conditions on the Response Amplitude Operator (RAO), Motion Sickness Incidence (MSI), and Motion-Induced Interruptions (MII) for a 300 GT Ro-Ro ferry. The hull model was developed using the Maxsurf Modeler based on the vessel's general arrangement drawings. The tank configurations, including the length, width, height, and position, were defined using Maxsurf Stability, which also provided the hydrostatic properties. Seakeeping simulations were conducted in Maxsurf



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Motion considering variations in ship speed (0 and 12 knots), wave height (3.0 and 3.5 m), and wave direction (0°, 90°, and 180°).

### 3.1. Vessel Motion Response (RAO)

RAO describes the oscillatory response of a vessel to wave excitation across a range of frequencies. Simulations in Maxsurf Motion considered remote location points, ship speed, heading, wave spectrum, hull geometry, draft and trim, mass distribution, damping coefficients, environmental conditions, frequency range, and the analysis method.

RAO evaluations were performed at three remote location points on the ship: the passenger, navigation, and vehicle decks, as shown in Figure 2. These locations were selected because of their significance in relation to passenger comfort, crew performance, and the overall operability of the vessel.

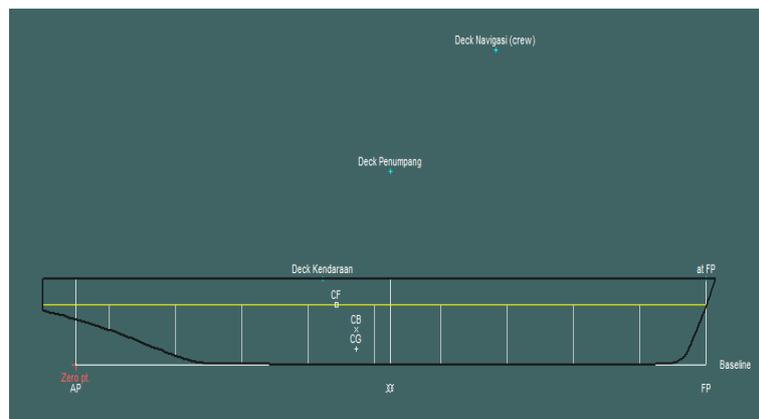


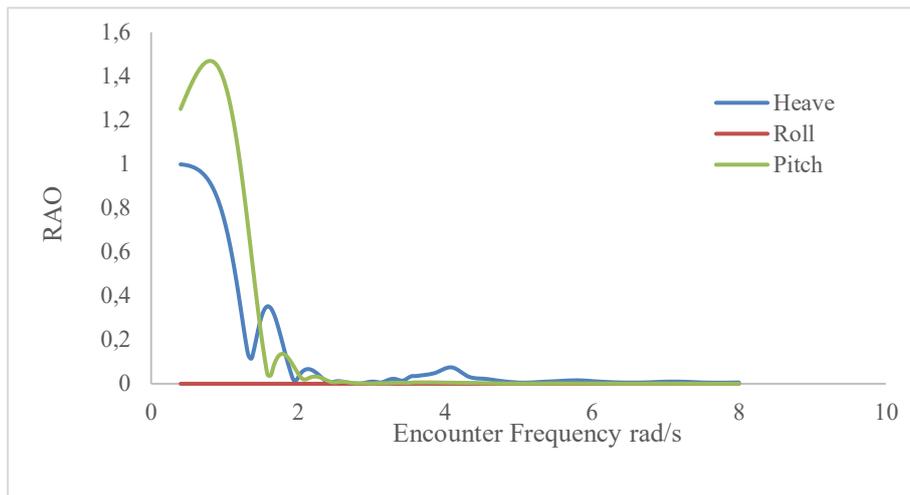
Figure 2. Remote Location Points on the Ship

The resulting motion responses under various sea states were compared with the NORDFORSK (1987) motion criteria to assess their acceptability in terms of comfort and safety.

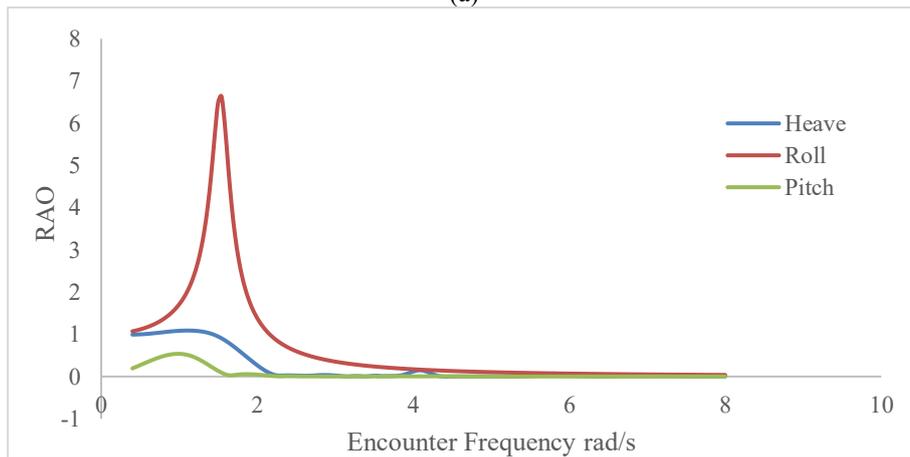
#### 3.1.1. Results of RAO Analysis at 0-Knots

At 0 knots, the RAO analysis revealed increased motion amplitudes in the 0.2–0.4 Hz resonance range. As illustrated in Fig. 3, the vessel motion responses vary significantly depending on the wave heading. The peak heave reached 1.089 m at a 90° heading (beam seas), roll reached 6.638° at the same heading, and pitch varied from 0.538° at a 90° heading to 1.469° at a 0° heading (Table 2).

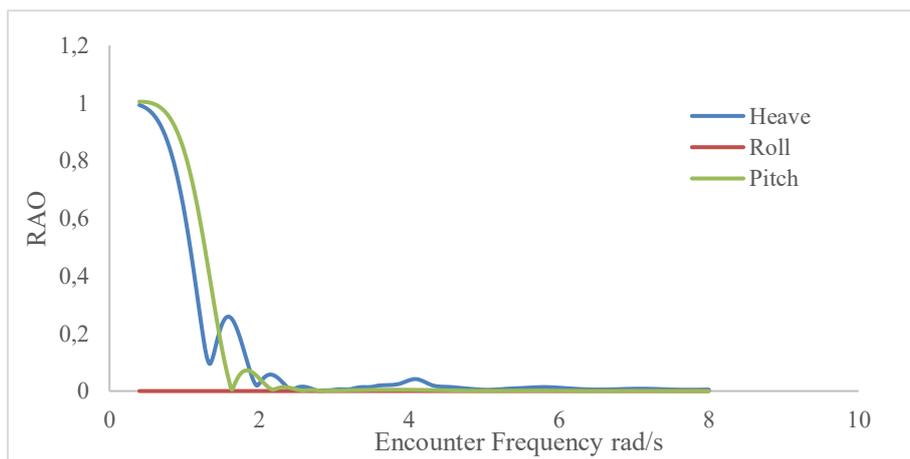
The comfort assessment based on NORDFORSK (1987) indicates that beam seas caused lateral accelerations of 0.490 g at  $H_s = 3$  m and 0.570 g at  $H_s = 3.5$  m, exceeding the allowable limit of 0.12 g. The roll at a 90° heading also exceeded the NORDFORSK limit of 6°, confirming beam seas as the most critical condition for passenger comfort and stability under stationary conditions. The following seas (0°) and head seas (180°) remained within acceptable limits (Table 3).



(a)



(b)



(c)

Figure 3. RAO Responses for Heave, Roll, and Pitch at (a) 0°, (b) 90°, and (c) 180° Wave Headings at 0-Knot Speed

Table 2. Peak RAO Motion Responses at 0-Knot Speed

Item	Heading	Motion	Unit
Heaving	0°	0.998	m.
	90°	1.089	m.
	180°	0.993	m.
Rolling	0°	0.000	deg.
	90°	6.638	deg.
	180°	0.000	deg.



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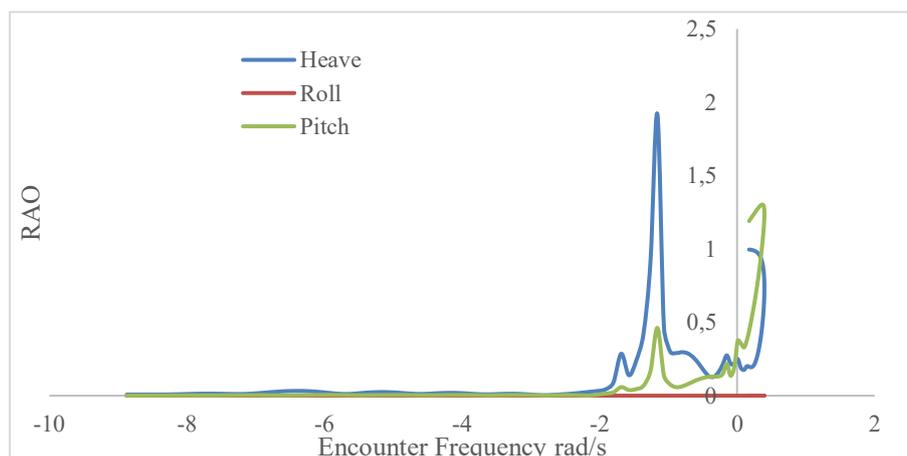
Item	Heading	Motion	Unit
	0°	1.469	deg.
Pitching	90°	0.538	deg.
	180°	1.005	deg.

Table 3. NORDFORSK Comfort Criteria (1987) at 12-Knot Speed

Heading	Hs	Criteria	Value	Units	RMS	Status
Following Seas	3 m	Vert. Acc at FP	≤ 0.275	g	0.072	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.071	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.
	3,5 m	Vert. Acc at FP	≤ 0.275	g	0.083	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.082	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.
Beam Seas	3 m	Vert. Acc at FP	≤ 0.275	g	0.083	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.073	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.490	exceeded
		Roll	≤ 6.0	deg.	9.970	exceeded
	3,5 m	Vert. Acc at FP	≤ 0.275	g	0.097	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.085	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.5698	exceeded
		Roll	≤ 6.0	deg.	11.600	exceeded
		Roll	≤ 6.0	deg.	11.600	exceeded
Head Seas	3 m	Vert. Acc at FP	≤ 0.275	g	0.095	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.050	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.
	3,5 m	Vert. Acc at FP	≤ 0.275	g	0.111	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.059	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.

### 3.1.2. Results of RAO Analysis at 12-Knots

At a vessel speed of 12 knots, the RAO analysis revealed a distinct motion response pattern compared to the stationary condition. Figure 4 illustrates the vessel's motion responses to wave headings of 0°, 90°, and 180°. The peak heave reached 1.920 m at a 0° heading (following seas), while the heave at a 90° heading (beam seas) was 0.999 m and at a 180° heading (head seas) was 1.192 m, as summarized in Table 4. The roll motion peaked at 6.638° at a 90° heading, and the pitch ranged from 0.652° at a 90° heading to 1.303° at a 0° heading. Beam seas continued to cause critical conditions, with lateral accelerations of 0.490 g at Hs = 3 m and 0.570 g at Hs = 3.5 m, which exceeded 0.12 g. The roll exceeded 6°, reaching 9.97° and 11.60°. Head seas (180°) also caused vertical accelerations above the NORDFORSK limits (0.348–0.405 g). Following seas (0°) remained within the comfort limits (Table 5).



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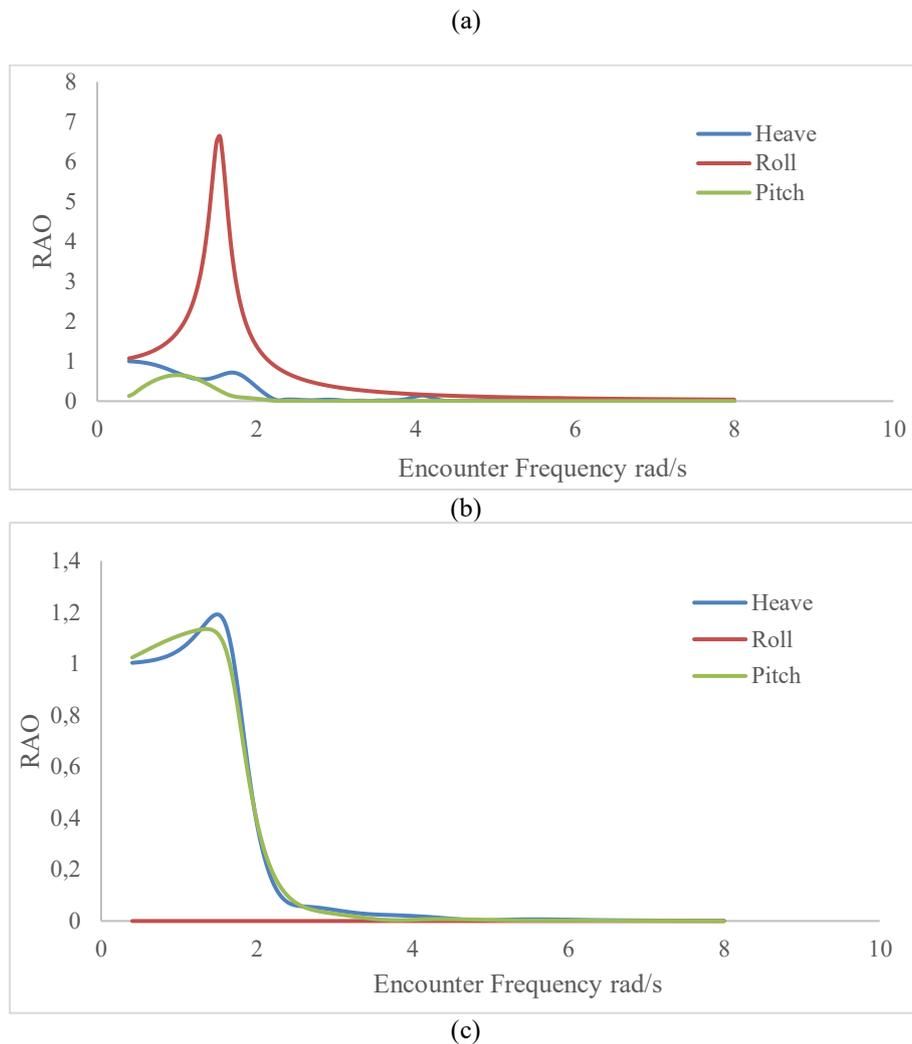


Figure 4. RAO Responses for Heave, Roll, and Pitch at (a) 0°, (b) 90°, and (c) 180° Wave Headings at 12-Knot Speed

Table 4. Peak RAO Motion Responses at 12-Knot Speed

Item	Heading	Motion	Unit
Heaving	0°	1.920	m.
	90°	0.999	m.
	180°	1.192	m.
Rolling	0°	0.000	deg.
	90°	6.638	deg.
	180°	0.000	deg.
Pitching	0°	1.303	deg.
	90°	0.652	deg.
	180°	1.135	deg.

Table 5. NORDFORSK Comfort Criteria (1987) at 12-Knot Speed

Heading	Hs	Criteria	Value	Units	RMS	Status
Following Seas	3 m	Vert. Acc at FP	≤ 0.275	g	0.040	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.038	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
	3,5 m	Roll	≤ 6.0	deg.	0.000	pass.
		Vert. Acc at FP	≤ 0.275	g	0.047	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.044	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.



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Heading	Hs	Criteria	Value	Units	RMS	Status
Beam Seas	3 m	Vert. Acc at FP	≤ 0.275	g	0.083	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.065	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.490	exceeded
		Roll	≤ 6.0	deg.	9.970	exceeded
	3,5 m	Vert. Acc at FP	≤ 0.275	g	0.097	pass.
		Vert. Acc. at Bridge	≤ 0.15	g	0.076	pass.
		Lat. Acc. at Bridge	≤ 0.12	g	0.570	exceeded
		Roll	≤ 6.0	deg.	11.600	exceeded
Head Seas	3 m	Vert. Acc at FP	≤ 0.275	g	0.348	exceeded
		Vert. Acc. at Bridge	≤ 0.15	g	0.281	exceeded
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.
	3,5 m	Vert. Acc at FP	≤ 0.275	g	0.405	exceeded
		Vert. Acc. at Bridge	≤ 0.15	g	0.328	exceeded
		Lat. Acc. at Bridge	≤ 0.12	g	0.000	pass.
		Roll	≤ 6.0	deg.	0.000	pass.

### 3.2. Motion Sickness Incidence (MSI) and Motion Induced Interruptions (MII)

Motion Sickness Incidence (MSI) and Motion-Induced Interruptions (MII) were evaluated to quantify onboard comfort at vessel speeds of 0 and 12 knots with wave headings of 0°, 90°, and 180°. Three monitoring locations were considered: the passenger, navigation, and vehicle decks. Simulations were performed using Maxsurf Motion, and the MSI values were obtained from analytical formulations combined with numerical results to ensure a comprehensive assessment of motion-induced discomfort.

#### 3.2.1. Passenger Deck

At 0-knot speed, the passenger deck experienced its most critical condition in beam seas (90° heading), where MSI Maxsurf reached 10.51%, MSI Formula was 3.16%, and MII peaked at 24.37 events/h at Hs = 3.5 m (Table 6). These values indicate a high likelihood of seasickness and significant disruption of passenger activities. In the following seas, MSI Maxsurf remained below 4%, Formula under 3.36%, and MII was 0 events/h, representing acceptable comfort conditions.

At 12 knots, following seas further improved comfort, with MSI Maxsurf and Formula dropping below 0.01% and 2%, respectively, and MII remained negligible (0 events/h; Table 7). Beam seas caused moderate discomfort, with Maxsurf ranging from 3.75% to 5.31%, Formula approximately 3–3.5%, and MII 20–24 events/h, highlighting roll-induced passenger motion. Head seas induced the most severe condition, with Maxsurf rising to 29.69%, Formula reaching 15.25%, and MII equal to 0 events/h, indicating an intense pitch-dominated motion affecting passenger comfort. Overall, following seas provide optimal comfort, beam seas moderate roll-dominated discomfort, and head seas generate severe pitch-dominated motions.

Table 6. MSI and MII Results on Passenger Deck at 0-Knot Speed

Angle	Hs	MII (event/hr)	MSI Maxsurf (%)	(SM)	MSI Formula (%)
Following Seas	3,0 m	0	2.4	1.15	2.93
	3,5 m	0	3.497	1.43	3.36
Beam Seas	3,0 m	20.43	7.814	2.352	3.14
	3,5 m	24.365	10.512	2.922	3.16
Head Seas	3,0 m	0	2.603	1.204	2.62
	3,5 m	0	3.774	1.497	3.01

Table 7. MSI and MII Results on Passenger Deck at 12-Knot Speed

Angle	Hs	MII (event/hr)	MSI Maxsurf (%)	(SM)	MSI Formula (%)
Following Seas	3,0 m	0	0.002	0.107	1.43
	3,5 m	0	0.004	0.134	1.63
Beam Seas	3,0 m	20.41	3.747	1.463	3.03
	3,5 m	24.352	5.306	1.817	3.48



Head Seas	3,0 m	0	24.237	6.421	13.27
	3,5 m	0	29.691	7.982	15.25

### 3.2.2. Navigation Deck

Vertical accelerations were more pronounced on the navigation deck, leading to discomfort levels similar to or higher than those on the passenger ones. At 0 knots, beam and head seas produced the most critical conditions. MSI Maxsurf reached 7.12–7.33%, Formula ranged 3.59–3.70%, and MII peaked at 32–33 events/h at  $H_s = 3.5$  m (Table 8). Following seas yielded lower MSI values (Maxsurf 5.11–7.08%, Formula 3.13–3.59%) with  $MII = 0$  events/h, representing acceptable comfort level.

At 12 knots, the following seas provided the lowest motion intensity, with  $MSI_{Maxsurf} < 0.01\%$ , Formula  $< 2\%$ , and MII negligible. Beam seas caused moderate discomfort (Maxsurf 2.35–3.42%, Formula 3.13–3.59%, MII 32–33 events/h), primarily because of the roll motion. Head seas induced the most severe motion, with Maxsurf, Formula, and  $MII = 0$  events/h rising to 37.66 %, 15.92 %, and the highest motion intensity across all decks, respectively.

Table 8. MSI and MII Results on the Navigation Deck at 0-Knot Speed

Angle	Hs	MII (event/hr)	MSI Maxsurf (%)	MSI Formula (SM)	MSI Formula (%)
Following Seas	3,0 m	0.000	5.109	1.768	3.13
	3,5 m	0.000	7.084	2.197	3.59
Beam Seas	3,0 m	32.554	5.138	1.774	3.22
	3,5 m	33.635	7.121	2.204	3.7
Head Seas	3,0 m	0.000	5.301	1.819	2.24
	3,5 m	0.000	7.332	2.621	2.57

Table 9. MSI and MII Results on the Navigation Deck at 12-Knot Speed

Angle	Hs	MII (event/hr)	MSI Maxsurf (%)	MSI Formula (SM)	MSI Formula (%)
Following Seas	3,0 m	0.000	0.005	0.137	1.41
	3,5 m	0.000	0.01	0.172	1.71
Beam Seas	3,0 m	32.346	2.346	1.115	3.13
	3,5 m	33.64	3.422	1.385	3.59
Head Seas	3,0 m	0.000	31.574	8.748	13.86
	3,5 m	0.000	37.662	10.872	15.92

### 3.2.3. Vehicle Deck

Located near the vessel's center of mass, the vehicle deck exhibited distinct motion behavior. Vertical accelerations were generally lower owing to proximity to the baseline, but roll motions in beam seas caused moderate MII values.

At 0 knots,  $MSI_{Maxsurf}$  remained below 13.21%, Formula ranged 2.63–3.61%, and MII reached 5.2 events/h at  $H_s = 3.5$  m in beam seas (Table 10); and following seas produced the most comfortable conditions, with Maxsurf 4.44–6.21%, Formula 2.63–3.01%, and  $MII = 0$  events/h. Beam seas caused moderate discomfort (Maxsurf 10–13.21%, Formula 3.15–3.61%, MII 2.99–5.21 events/h), highlighting the effect of lateral accelerations on cargo handling. Head seas generated lower MSI (Maxsurf 3.32%, Formula 3.18%) and  $MII = 0$  events/h, indicating a mild motion intensity.

At 12 knots, the following seas remained favorable, with  $Maxsurf < 0.01\%$ , Formula  $< 2\%$ , and  $MII = 0$  events/h. Beam seas caused moderate discomfort (Maxsurf 5.99–8.21%, Formula 3.11–3.56%, MII 2.99–5.25 events/h), showing a roll-dominated motion affecting cargo and crew activity. Head seas induced the most critical condition, with Maxsurf rising to 26.74%, Formula reaching 15.24%, and  $MII = 0$  events/h, confirming a severe pitch-dominated motion on the vehicle deck.



Table 10. MSI and MII Results on the Vehicle Deck at 0-Knot

Angle	Hs	MII (MII/hr)	MSI Maxsurf (%)	MSI Formula (SM)	MSI Formula (%)
Following Seas	3,0 m	0.000	4.438	1.636	2.63
	3,5 m	0.000	6.213	2.034	3.01
Beam Seas	3,0 m	2.994	10.002	2.816	3.15
	3,5 m	5.205	13.206	3.498	3.61
Head Seas	3,0 m	0.000	2.273	1.121	2.77
	3,5 m	0.000	3.323	1.394	3.18

Table 11. MSI and MII Results on the Vehicle Deck at 12-Knot

Angle	Hs	MII (event/hr)	MSI Maxsurf (%)	MSI Formula (SM)	MSI Formula (%)
Following Seas	3,0 m	0.000	0.002	0.117	1.41
	3,5 m	0.000	0.005	0.145	1.61
Beam Seas	3,0 m	2.989	5.989	1.962	3.11
	3,5 m	5.247	8.213	2.437	3.56
Head Seas	3,0 m	0.000	21.585	5.671	13.26
	3,5 m	0.000	26.735	7.050	15.24

### 3.3. Comparison with Previous Study

The seakeeping assessment of the 300 GT Ro-Ro ferry demonstrated that vessel motion, passenger comfort, and crew operability were strongly influenced by wave heading, sea state, and vessel speed.

Vessel Motion Response (RAO) – Compared with larger ferries, the 300 GT vessel exhibits substantially higher roll and pitch responses in beam and head seas. For instance, previous studies reported roll angles of 2.41°–2.87° for 500–1300 GT Ro-Ro ferries under similar conditions [24], [25], whereas the present 300 GT ferry shows amplified roll and lateral accelerations owing to its smaller displacement, shorter length, and higher windage-to-draft ratio. This confirms that smaller ferries are more sensitive to wave excitation, particularly in the beam sea.

Passenger Comfort (MSI & MII) – Motion-induced discomfort on the passenger and navigation decks is considerably higher than that on larger vessels. Beam seas at low speed and head seas at service speed produce the most critical conditions, with frequent motion interruptions, as reflected in elevated MII values. Although the vehicle deck is less affected by vertical motion, it still experiences notable lateral accelerations in beam seas. These results align with the RAO trends and underscore that smaller Ro-Ro ferries are more prone to motion sickness and operational disruption, particularly on the upper decks.

Implications from Comparison: Relative to larger ferries, the 300 GT vessel requires careful operational planning. Avoiding beam and head seas when possible, selecting favorable wave headings, and maintaining moderate cruising speeds are critical strategies for mitigating passenger discomfort and ensuring crew performance. The comparison highlights that smaller ferries are inherently more sensitive to seakeeping challenges, emphasizing the need for design considerations that prioritize their stability and comfort.

The seakeeping analysis of the 300 GT Ro-Ro ferry revealed that vessel motion, passenger comfort, and crew operability were strongly influenced by wave heading, sea state, and vessel speed.

### 3.4. Summary and Design Implications

The simulation results revealed that vessel motion responses, specifically the RAO, MSI, and MII, were substantially influenced by the wave heading, significant wave height, and vessel speed. Under stationary conditions (0 knot speed), beam seas (90° heading) consistently produced the most severe responses, including roll amplitudes reaching 11.6° and lateral accelerations of up to 0.5698 g. These values exceeded the comfort thresholds defined by NORDFORSK [26]. Correspondingly, the highest MSI and MII values were observed on the passenger and navigation decks, indicating a significant risk to crew performance and onboard safety during these periods.

At a cruising speed of 12 knots, reductions in the heave and pitch responses were observed, which were attributed to changes in the wave encounter frequencies. Nevertheless, head seas (180° heading) introduced new challenges, with vertical accelerations measured at the forepeak and bridge exceeding the acceptable



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limits. The MSI levels reached 15.25% on the passenger deck and 15.92% on the navigation deck, indicating that motion-induced discomfort can remain critical even under normal operational conditions.

Based on these findings, the following recommendations are proposed for design and operational improvements:

- Beam seas should be avoided during low-speed or drifting conditions to minimize excessive roll and lateral accelerations.
- Moderate cruising speeds should be maintained to reduce heave and pitch responses while avoiding prolonged exposure to head seas under high-wave conditions.
- Prioritize lower-deck areas, such as the vehicle deck, for critical operations and equipment placement owing to reduced motion exposure.
- The implementation of stabilization systems, including passive devices (e.g., bilge keels) or active systems (e.g., fin stabilizers), and optimized routing strategies to enhance onboard comfort and operational reliability should be considered. It should be noted that these suggestions are theoretical and based on simulation results, and have not been experimentally validated on the analyzed vessel.

#### 4. CONCLUSION

This study showed that the seakeeping performance of a 300 GT Ro-Ro ferry is significantly affected by wave direction and speed. RAO analysis indicated compliance with NORDFORSK [26] limits in following and head seas, but excessive roll amplitudes up to  $5.6^\circ$  occurred in beam seas, reducing comfort and stability. MSI results based on ISO 2631 generally remained within the moderate zone, though at 12 knots in head seas values entered the alert range, increasing seasickness risk, while MII analysis classified most interruptions as “possible” except in beam seas, where they became “probable.” These findings emphasize beam seas as the most critical challenge, with practical implications for route planning, maintaining moderate cruising speeds, allocating critical operations to lower decks, and considering stabilization systems, motion prediction, and weather routing to enhance passenger comfort and operational safety.

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