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研究課題名（和文）Multiphysics modelling and experimental verification of a suspension ship running at head seas

研究課題名（英文）Multiphysics modelling and experimental verification of a suspension ship running at head seas

研究代表者

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研究成果の概要（和文）：正面波中にサスペンション船の運動応答を数値計算と実験検証の組み合わせを用いて検討した。ツインハルに作用する流体力係数と波による力/モーメントは、OrcaWaveを使用して計算されました。前進速度の変化に応じて波強制力/モーメントをゼロ速度で得られたデータを基にして推定する手法を構築した。キャビンとハルのヒーブとピッチ運動応答に関して、実験と計算の間で合理的な一致が得られました。さらに、サスペンション船が特有の設計パラメータが初期横安定性に与える影響を数値的に調べた。キャビンとハルの質量比を減らす、キャビンの積載高さを減らす、船の幅を広げるなどが初期横安定性を向上させることが分かった。

研究成果の学術的意義や社会的意義

This research could offer a valuable understanding of the multidisciplinary mechanisms governing the motion dynamics of suspension ships, and stimulate the development of innovative marine suspension technology to improve safety by understanding the influence of design parameters on stability.

研究成果の概要（英文）：This study investigates the motion responses of a suspension catamaran in head waves, employing a combination of numerical calculations and experimental validation. Hydrodynamic coefficients and wave-exciting forces/moments acting on the twin-hull were determined using the OrcaWave. An estimation method was introduced to extrapolate wave-exciting forces/moments at varying advancing speeds based on data derived at zero speed. Reasonable agreement is obtained between the experiments and calculation regarding the heave and pitch motion responses of both the cabin and the hull. Moreover, the impact of the design parameters specific to suspension ships on the initial transverse stability is numerically investigated. It is found that enhancing the initial transverse stability can be achieved through several means: decreasing the mass ratio between the sprung and unsprung bodies, reducing the loaded height of the suspension, and increasing the beam of the ship.

研究分野：船舶海洋工学関連

キーワード：Suspension Ship　Motion Control　Catamaran　Numerical Analysis　Transverse Stability　Ship Design　Model Experiment　Hydrodynamic Coefficient

１．研究開始当初の背景

The pursuit of stability and enhanced ride comfort in small vessels has long been a paramount concern. While suspension technology has been effectively utilized in land vehicles, its application in small vessels to reduce ship motions is a relatively new concept. Since 2008, various suspension system designs have emerged, giving rise to a novel ship type known as suspension ship. This innovative vessel comprises three main components: a cabin section, a hull section, and a suspension system positioned between them.

By employing suspension technology, the motion responses of the cabin can be decoupled from those of the hull, resulting in different amplitudes and phases. This ability to extend and compress the suspension offers promising prospects for mitigating motion discomfort. However, despite promising experimental results showing significant motion reduction, comprehensive quantitative research on suspension ship design and dynamic motion responses remains lacking. This gap in knowledge represents a bottleneck in fully understanding the capabilities and underlying mechanism of suspension ships.

２．研究の目的

This research is aiming to develop a multibody dynamic simulation for suspension ships, which is capable to make reasonable predictions about the motion responses of the cabin and the hull at various head wave conditions under different motion control modes. Meanwhile, the decision-making framework for suspension ship design will be formulated through extensive numerical analyses focusing on stability assessments. This is expected to provide comprehensive understandings of marine suspension technology and stimulating innovative ideas on addressing marine challenges.

３．研究の方法

(1) Simulation of Hydrodynamic Coefficient

The mesh for the twin-hull was created using Rhinoceros® software, as depicted in Fig.1. Hydrodynamic parameters including added mass, damping coefficient, and restoring force constant, as well as wave loads, were computed at different time periods at zero speed utilizing OrcaWave, employing panel method within the boundary element method framework. Then, an approximation method was introduced to predict wave loads under a non-zero advancing speeds.

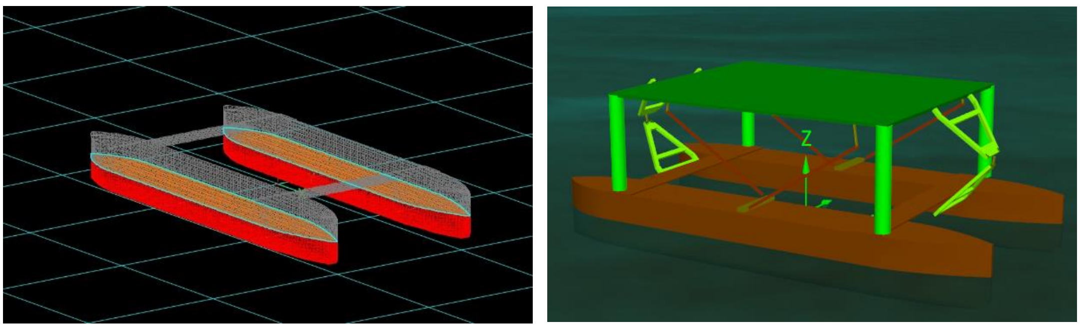


Figure 1. Mesh of the twin-hull (left) and numerical model (right) of the suspension ship.

(2) Numerical Calculation of Motion Responses

The equations of motion governing the cabin and the twin-hull are derived. A dynamic framework of suspension ships is shown in Fig.2 Within this dynamic framework, the control force exerted by the suspension system is characterized by spring force and damping force. These forces are directly proportional to the deformation distance and velocity of the springs, respectively. Notably, the control force acts simultaneously on both the cabin and the twin-hull in opposite directions with equal magnitude. The external force acting on the cabin is solely represented by the control force. Conversely, for the twin-hull, the external force comprises the resultant force of wave loads in addition to the control force.

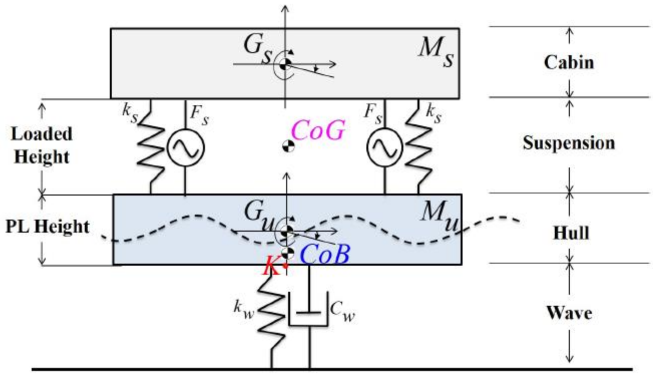


Figure 2. Dynamic framework of suspension ships.

(3) Verification using Experimental Results

Verification of the numerical results was done by making comparison with the experimental results in terms of the hydrodynamic coefficients, wave loads, and motion responses.

(4) Numerical Analysis of Stability of Suspension Ships

New design parameters are introduced while utilizing suspension systems in suspension ships, which could cause new challenges to sustain stability of suspension ships. These parameters are identified and their impact on the transverse metacentric height is analyzed using a monohull suspension model as the basis.

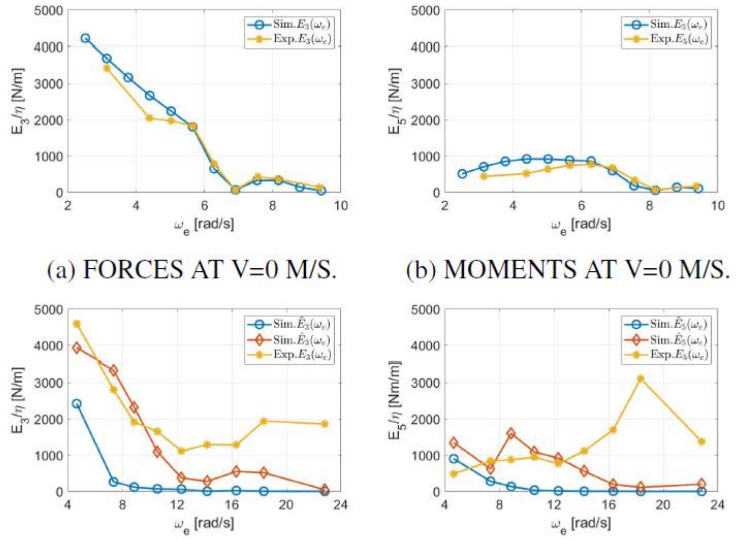
４．研究成果

This study investigates the motion responses of a suspension catamaran in head waves, employing a combination of numerical calculations and experimental validation. Hydrodynamic coefficients and wave-exciting forces/moments acting on the twin-hull were determined using the OrcaWave potential flow solver. An estimation method was introduced to extrapolate wave-exciting forces/moments at varying advancing speeds based on data derived at zero speed. Moreover, the impact of the design parameters specific to suspension ships on the initial transverse stability is numerically investigated. The main conclusions are summarized as follows.

(1) Comparison of Hydrodynamic Coefficient and Wave Loads

In Figs.3a and 3b, the comparison between wave exciting force/moments derived from numerical simulation and tank experiments show reasonable agreement at zero forward speed. In

Figs.3c and 3d, within the relatively lower frequency range, the approximated wave exciting forces/moments closely align with the experimental results. However, as frequencies increase, the approximated values are notably smaller than the experimental ones. Despite this discrepancy, the proposed approximation method (orange line) effectively mitigates the difference between the numerical (yellow line) and the experimental (blue line) results.



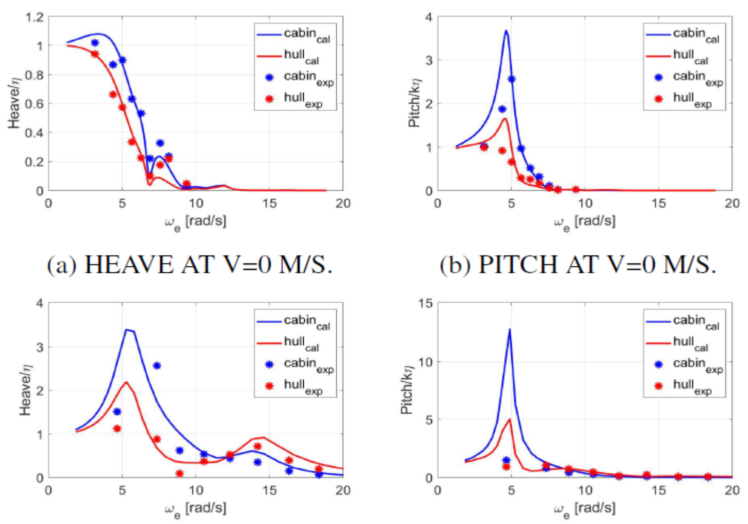
(a) FORCES AT V=0 M/S. (b) MOMENTS AT V=0 M/S.

(c) FORCES AT V=1.5 M/S. (d) MOMENTS AT V=1.5 M/S.

Figure 3. RAO comparison of wave exciting forces and moments.

(2) Comparison of Motion Responses

In Fig.4, reasonable agreement is obtained between the experiments and calculation regarding the heave and pitch motion responses of both the cabin and the hull. At zero towing speed, both the heave and pitch motions of the cabin are larger than those of the hull. This can also be observed in the pitch motion at the towing speed of 1.5 m/s. However, as depicted in Fig.5c it becomes apparent that the heave motion of the cabin exceeds that of the hull within the lower frequency domain, it becomes smaller within the higher frequency domain. This consistent tendency is observed both in experimental and computational results.



(a) HEAVE AT V=0 M/S. (b) PITCH AT V=0 M/S.

(c) HEAVE AT V=1.5 M/S. (d) PITCH AT V=1.5 M/S.

Figure 4. Motion responses of the cabin and the hull at free mode.

(3) Discussion on Initial Stability

It is found that enhancing the initial transverse stability can be achieved through several means: decreasing the mass ratio between the sprung and unsprung bodies, reducing the loaded height of the suspension, and increasing the beam of the ship in a monohull configuration or the overall beam of the ship in a catamaran configuration. Among these parameters, the beam of ship is the most influential factor. The comparison between catamaran and monohull configurations highlights the challenge of achieving adequate initial transverse stability with a fully suspended cabin in a monohull. This observation tells why existing suspension ships predominantly adopt catamaran configuration.

５．主な発表論文等

〔雑誌論文〕　計2件（うち査読付論文　2件／うち国際共著　0件／うちオープンアクセス　1件）

１．著者名 Han Jialin、Kitazawa Daisuke、Murai Motohiko	４．巻 7
２．論文標題 Numerical Simulation of Motion Responses of a Cabin-Suspended Catamaran in Head Waves	５．発行年 2023年
３．雑誌名 Proceedings of ASME 2023 42nd International Conference on Ocean, Offshore and Arctic Engineering	６．最初と最後の頁 -
掲載論文のDOI（デジタルオブジェクト識別子） 10.1115/OMAE2023-103284	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 -

１．著者名 Han J、Murai M	４．巻 1294
２．論文標題 A parametric study on the initial transverse stability of suspension ships	５．発行年 2023年
３．雑誌名 IOP Conference Series: Materials Science and Engineering	６．最初と最後の頁 012021～012021
掲載論文のDOI（デジタルオブジェクト識別子） 10.1088/1757-899X/1294/1/012021	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 -

〔学会発表〕　計2件（うち招待講演　0件／うち国際学会　2件）

１．発表者名 Jialin Han
２．発表標題 Numerical Simulation of Motion Responses of a Cabin-Suspended Catamaran in Head Waves
３．学会等名 ASME 2023 42nd International Conference on Ocean, Offshore and Arctic Engineering（国際学会）
４．発表年 2023年

１．発表者名 Jialin Han
２．発表標題 A parametric study on the initial transverse stability of suspension ships
３．学会等名 The International Conference on Computational Methods and Ocean Technology (COTech) 2023（国際学会）
４．発表年 2023年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関