HYDRODYNAMIC RESPONSE OF LARGE FLOATING STRUCTURES IN SHORT-CRESTED WAVES : A THEMATIC REVIEW

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ABSTRACT

Research has indicated that the motion and load response induced by short-crested waves on floating structures differs from that caused by long-crested waves even at the same sea state level. Despite the significant effect of short-crested waves on the motion response of large floating structures, no review paper has addressed the methods and approaches used in the hydrodynamic analysis study of large floating structures. This review was motivated by the belief that the hydrodynamic response of large floating structures in short-crested waves needs to innovate with a more in-depth investigation of the method used in the analysis. Therefore, this systematic review aims to synthesize the literature between 2010 and 2020 on hydrodynamic analysis methods of large floating structures in short waves with ATLAS.ti 8. Seventy-five peer-reviewed journal articles were identified through a keyword search using four basic search options: search process, wildcard, truncation, and the boolean SCOPUS and Web of Science (WOS) databases. Nevertheless, only 21 articles were shortlisted after the inclusion and exclusion process. A themed review of these 21 articles identified 15 initial codes that characterize the hydrodynamic analysis of large floating structures in short-crested waves. They were grouped into three clusters: numerical analysis, experimental analysis, and numerical and experimental analysis. The results will benefit future studies as a reference on hydrodynamic analysis of large floating structures in short-crested waves.

Keywords: *short-crested wave, long-crested wave, hydrodynamic response, ATLAS.ti 8, thematic review*

1 INTRODUCTION

Research has indicated that the motion and load response induced by short-crested waves on floating structures differs from that caused by long-crested waves even at the same sea state level.[1] the authors brought up in their research, up to the present time, that the majority of numerical and experimental motion response of a floating structure is focused on the response in two-dimensional long-crested waves. Although, the realistic sea waves are three-dimensional short-crested waves. Some research articles [2] stated the overestimation or overprediction of wave forces obtained by the long-crested waves.

[3] and [4] joined the industry project "Short-CresT" to study the short-crestedness of waves. Their project searched, assembled, and utilized the best directional wave measurements worldwide, consisting of 527,610 sea-states worth of directional and spectra parameters. Their study provided evidence that no parameters can be used to distinguish the mean or peak of short-crested waves on sea-state levels. Also, no relationship was found between the motion amplitude and maximum wave crested. Their study consolidated the experiment found, which did not find any relation between the parameters of sea-state derived from the frequency spectra. The conclusion made from the outcome was that the statics, kinematics, and loading of short-crested waves differ significantly from long-crested waves usually used in the design of offshore structures.

[5] covered the most important study in short-crested waves where he performed a numerical diffraction calculation on a fixed vertical circular cylinder due to the incident of short-crested waves. [6] defined the short-crested waves as the waves of the finite lateral extent and exhibit different properties to plane waves, especially the nonlinear short-crested waves. [7] defined the short-crested waves like a regular three-dimensional wave field, containing two components propagating at an oblique angle to each other. [8] who covered the research of short-crested wave diffraction by a vertically fixed cylinder mentioned that the definition of a short-crested wave is an expected three-dimensional wave [9] model that describes waves generated by winds blowing across the ocean's surface. [9], [10], and [11] described the definition of short-crested waves as could be doubly periodic in two horizontal directions, one in the direction of propagation and the other normal to it.

Various researchers have interpreted short-crested waves in different ways, but their points are mutually supportive. A short-crested wave is defined by [12] as a series of long-crested waves with random magnitude and direction. [2] expanded the definition by which a short-crested wave is defined as the linear summation of a series of long-crested waves propagated to different rules, where the magnitude and direction are randomly generated. [13] supported this interpretation in their work on the numerical simulation of ship-shape FPSO wave loading under different wave conditions. Nevertheless, ocean waves are three-dimensional short-crested waves subject to nonlinearity, randomness, and directional propagation [14].

Despite the precision of short-crested waves compared to long-crested waves, no review paper has addressed the approach and method used to evaluate the motion response of large floating structures. Therefore, this review was motivated by the belief that the hydrodynamic response of an extensive floating system in short-crested waves requires a more in-depth study of the method used in the analysis. The objectives of the paper are to conduct a systematic literature review of short-crested wave analysis due to the hydrodynamic response of large floating structures from 2010 to 2020 and discuss the methods used in the current approach based on the following question:

RQ: What are the current approaches and methods of hydrodynamic analysis of large floating structures in short-crested waves discussed in publications from 2010 to 2020?
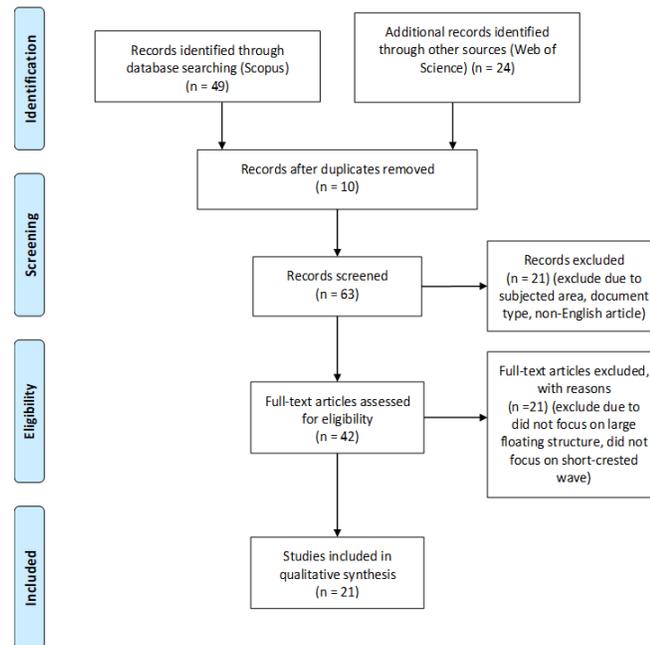
2 MATERIALS AND METHODS

Figure 1: Inclusion and exclusion flow of the study [15]

The term thematic review using ATLAS.ti as introduced by [16] was implemented because the study method applied the thematic analysis procedure in the literature review. [17] defined thematic analysis as a process of identifying method and approach themes over thorough reading on the subject. The following step determines the pattern and constructs category to understand the analysis trend of large floating structures in short-crested waves. The tenets of the research serve to analyze and interpret the findings for the current phenomenon concerning the hydrodynamic response of an extensive floating system in short-crested waves. The selection of literature was performed according to several selection criteria. The published articles were extracted from the Scopus database using the keyword TITLE-ABS-KEY (("Short-crest* wave*") AND ("FPSO*" OR "SPAR*" OR "Semi-submersible*" OR "FLNG*" OR "Vessel*" OR "TLP*" OR "Ship*))" OR "platform*")) AND PUBYEAR > 2010. Web of Science (WoS) database was also used to retrieve the published articles using keyword (("Short-crest* wave*") AND ("SPAR*" OR "FPSO*" OR "semi-submersible*" OR "FLNG*" OR "vessel*" OR "TLP*" OR "ship*" OR "platform*")) and Refined by: PUBLICATION YEARS: (2019 OR 2014 OR 2018 OR 2013 OR 2017 OR 2012 OR 2016 OR 2011 OR 2015 OR 2010).

Table 1: Search strings Scopus and WoS for the publication year 2010 to 2020.

Database	Keyword TITLE-ABS-KEY	No. of article
SCOPUS	(("Short-crest* wave*") AND ("FPSO*" OR "SPAR*" OR "Semi-submersible*" OR "FLNG*" OR "Vessel*" OR "TLP*" OR "Ship*))" OR "platform*"))	49

Web of Science (WoS)	(("Short-crest*wave*") AND ("SPAR*" OR "FPSO*" OR "semisubmersible*" OR "FLNG*" OR "vessel*" OR "TLP*" OR "ship*" OR "platform*"))	24

It is culminated in about 73 publications taking into account results from the two Scopus and WoS databases. Scopus was the central database used in the review, which is one of the largest databases covering more than 22 800 journals from 5 000 publishers worldwide. Meanwhile, as the second database used in this review, WoS consists of more than 33 000 journals with over 256 disciplines. As this review was limited to peer-reviewed journals and proceeding articles, 31 were removed after careful screening, including ten duplicate reports. In the next stage, out of 42 articles eligible to be reviewed, a total of 21 articles were excluded due to not focusing on large floating structures and not concentrating on short-crested waves. Finally, the review analysis resulted in 21 publications (see Figure 1).

The next step is the transition of all 21 papers saved in metadata from Mendeley to ATLAS.ti 8 as primary documents. Several groups were automatically initiated in the code category from metadata built in Mendeley, as shown in Figure 2. The ATLAS.ti 8 identification made the sorting much simpler and more systematic. Fifteen initial codes were developed in the first round of coding. The codes were then grouped into several themes (Theme 1: Numerical Analysis, Theme 2: Experimental Analysis, Theme 3: Numerical and Experimental Analysis) to answer the research question "What are the current approaches and methods of hydrodynamic analysis of large floating structures in short-crested waves discussed in the publications from 2010 to 2020?" and contributed to a final of three main categories. The findings of this review analysis were divided into two parts: quantitative results and qualitative results.
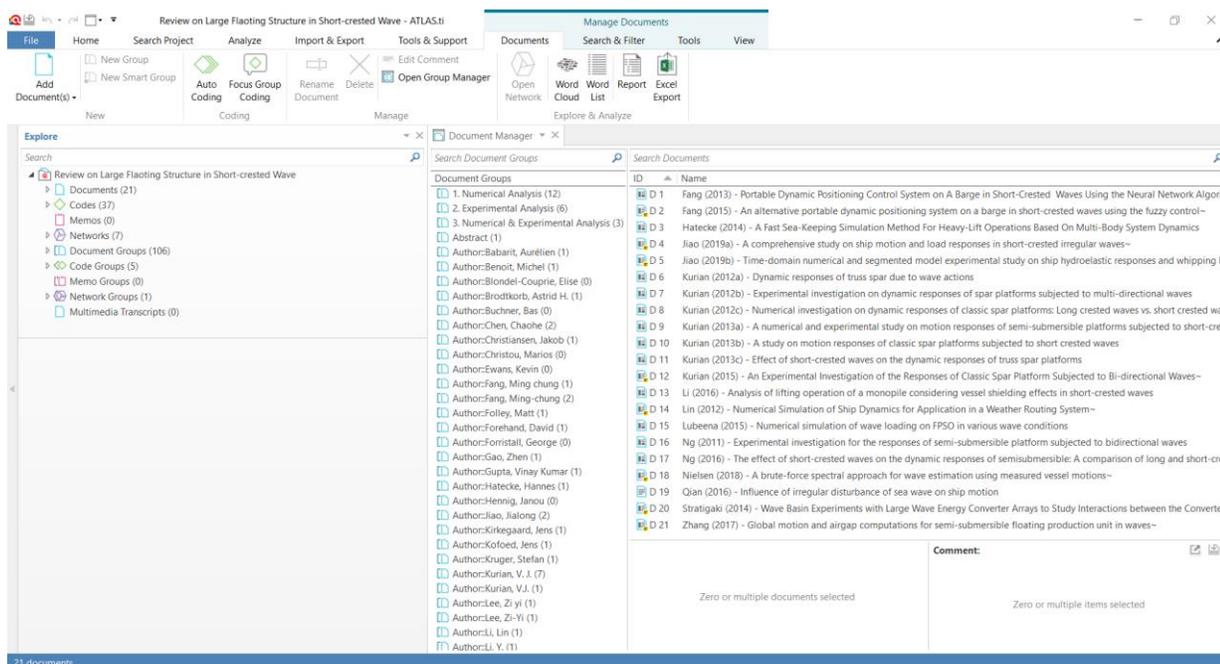

Figure 2: Code group formed from Mendeley metadata.

In ATLAS.ti, all 21 articles were simulated to obtain the word frequency in all papers to ensure their relevance for review analysis. Figure 3 shows the word cloud with high frequency or word repetition generated from 21 articles to be reviewed. All the words in the word cloud showed that the 21 articles to be reviewed were relevant. The words "wave," "short-crested," "response," and others led to the high-frequency words in these 21 articles.
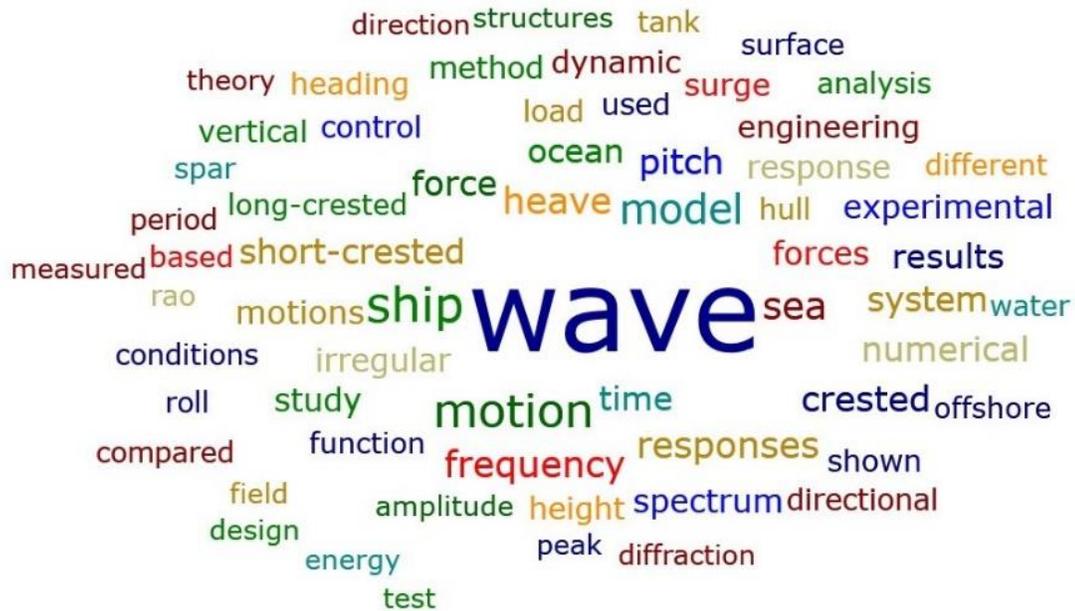

Figure 3: Word cloud generated from 21 articles.

3. RESULTS AND DISCUSSIONS

3.1 Quantitative Analysis

Research on large floating structures in short-crested waves has been scarcely found in scientific and research publications. Throughout the systematic literature search, very few studies were found that analyzed large floating structures in short-crested waves. However, the actual sea condition is accurate to describe in short-crested waves. From 2010 to 2020, the systematic search of scientific and research publications on large floating structures in short-crested waves showed only several articles, as shown in Figure 4.

As database implementation is static and the use of the phrase "short-crested wave" and the phrases of all types of large floating structures ("Ship," "Semi-submersible," "SPAR," "FPSO," "TLP," "FLNG") is limited in the ocean and offshore research, proceedings and theses were also included to assess trends and patterns. Although the paper was intended for large floating structures in short-crested waves, the journals indicated that the articles published vary. Table 1 shows that these research strings were referenced in several periodicals through the 21 articles' identification. The hydrodynamic analysis of large floating structures in short-crested waves was then carried out through a critical review of the results from the study of method application in the hydrodynamic response of large floating structures in short-crested waves. Figure 4 shows that the publication trend has seen inconsistency and fluctuation year after year. In 2010, no publications underlined the hydrodynamic response of large floating structures due to short-crested

waves. Nonetheless, the numbers increased every year until 2013, while no record was found in any publications at the time this paper was.
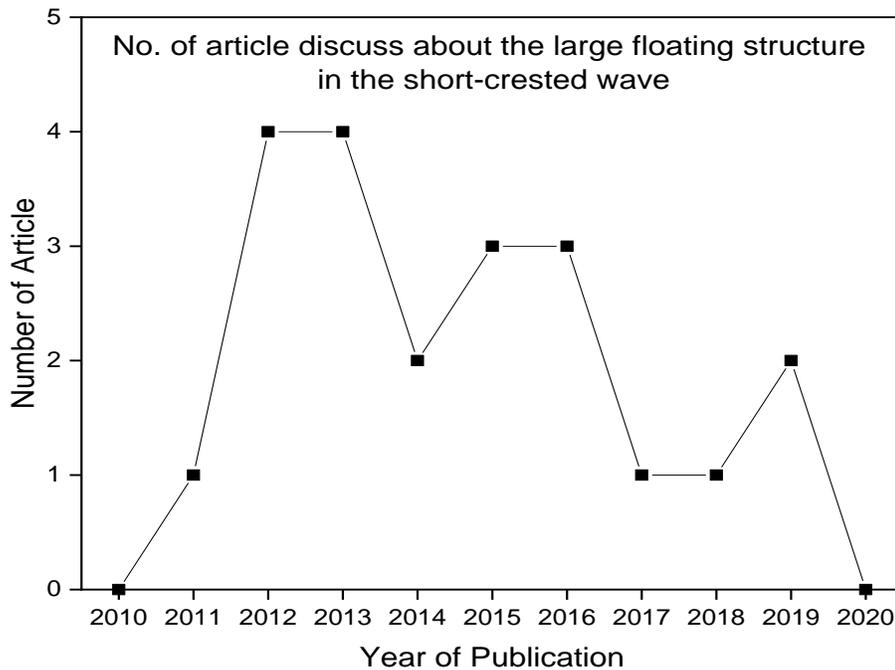

Figure 4: Paper breakdown according to the year of publication.

An iterative process of comparing the 21 research articles for similarities and differences was made to achieve homogeneity in the resulting sub-categories. Table 2 provides a list of publications and their distribution in sub-categories. Furthermore, the analysis methods of large floating structures in short-crested waves carried out so far were investigated. The research articles concentrated on the methods used to present the hydrodynamic response of an extensive floating system. The initial coding of 15 codes was categorized into three main themes: Numerical Analysis, Experimental Analysis, and Numerical and Experimental Analysis. These themes were divided into types of floating structures, as shown in Table 2, so that a detailed and comprehensive review analysis study can be done.

Table 1 : Articles reviewed based on journals

	2011	2012	2013	2014	2015	2016	2017	2018	2019
National Postgraduate Conference - Energy and Sustainability: Exploring the Innovative Minds, NPC 2011	1								
IEEE Business, Engineering and Industrial Applications Colloquium, 2012		1							
IEEE Business Engineering and Industrial Applications Colloquium, 2013			1						
China Ocean Engineering			1						
IEEE Colloquium on Humanities, Science and Engineering Research, 2012		1							
Energies				1					
Engineering Challenges for Sustainable Future - Proceedings of the 3rd International Conference on Civil, offshore and Environmental Engineering, 2016						1			
International Journal of Naval Architecture and Ocean Engineering									1
International Journal of Offshore and Polar Engineering						1			
Jiaotong Yunshu Gongcheng Xuebao/Journal of Traffic and Transportation Engineering						1			
Journal of Vibrational Engineering and Technologies			1						
Marine Structures								1	
Ocean Engineering							1		1
Ocean Systems Engineering					1				
Offshore Geotechnics; Ronald W. Yeung Honoring Symposium on Offshore and Ship Hydrodynamics, 2012		1							
Proceedings of the Annual Offshore Technology Conference, 2015					1				
International Conference on Ocean, Offshore and Arctic Engineering OMAE, 2014				1					
International Offshore and Polar Engineering Conference, ISOPE, 2014			1						

Research Journal of Applied Sciences, Engineering and Technology	1			1				

Table 2: Documents on types of floating structures and their methods of analysis.

Type of Floating Structure	Barge	Classic SPAR	FPSO (ship-shape)	Heavy-lift Vessel	Semi-submersible	Semi-submersible	Ship	Truss SPAR	Wave Energy Converter
Fang & Lee, (2013)	N								
Fang & Lee, (2015)	N								
Hatecke et al., (2014)				N					
Jiao et al., (2019a)							E		
Jiao, Yu, et al., (2019b)							N&E		
Kurian et al., (2012a)								N	
Kurian et al., (2012c)		E						E	
Kurian et al., (2012c)		N							
Kurian et al., (2013a)					N&E				
Kurian et al., (2013c)		E							
Kurian et al., (2013c)								N&E	
Kurian et al., (2015)		E							
Li et al., (2016)				N					
Lin & Fang, (2012)							N		
Lubeena et al., (2015)			N						
Ng et al., (2011)					E				
Ng & Ng, (2016)					N				
Nielsen et al., (2018)							N		
Qian et al., (2016)							N		
Stratigaki et al., (2014)									E
Zhang et al., (2017)						N			

Methods of Analysis
N = Numerical Analysis
E = Experimental Analysis
N&E = Numerical and Experimental Analysis

The model was evaluated using the year and type of floating structure from the analysis methods of hydrodynamic response in short-crested waves, as shown in Table 3. The giant floating establishments were classified in to nine types: barge, classic SPAR, FPSO (ship-shape), heavy-lift vessel, semi-submersible (six-circular column), semi-submersible (symmetrical), ship, truss SPAR, and wave energy converter. The articles found trends of domination in the numerical analysis method on large floating structures due to short-crested waves for the last ten years. It has been mainly used and still relevant in involving many types of large floating structures since 2012. The pattern on experimental analysis from 2012 to 2015 is still appropriate as part of the method to analyze the hydrodynamic response of large floating structures in short-crested waves, even though there was no publication from 2016 to 2018. The high cost of experimental analysis has made numerical analysis the dominating method over the years. Five types of large floating structures were involved in the study of short-crested waves: classic SPAR, truss SPAR, semi-submersible (symmetrical), ship, and wave energy converter.

Meanwhile, numerical and experimental analysis due to the hydrodynamic response of large floating structures in short-crested waves is rarely found in scientific publications despite being the best approach. Although there are some drawbacks, such as cost and time factors, the combination of numerical and experimental analysis methods is still a potential research tool for hydrodynamic analysis of large floating structures in natural short-crested sea waves. The truss SPAR, semi-submersible (symmetrical), and ship have been involved in this method analysis for the past ten years.

Table 3: The themes and types of floating structures according to year.

Methods of Analysis/Types of Floating Structure		2011	2012	2013	2014	2015	2016	2017	2018	2019	TOTAL
Numerical Analysis	**B**			1		1					11
	CS		1								
	FSS					1					
	HLV				1		1				
	SS							1			
	S		1				1		1		
	TS		1								

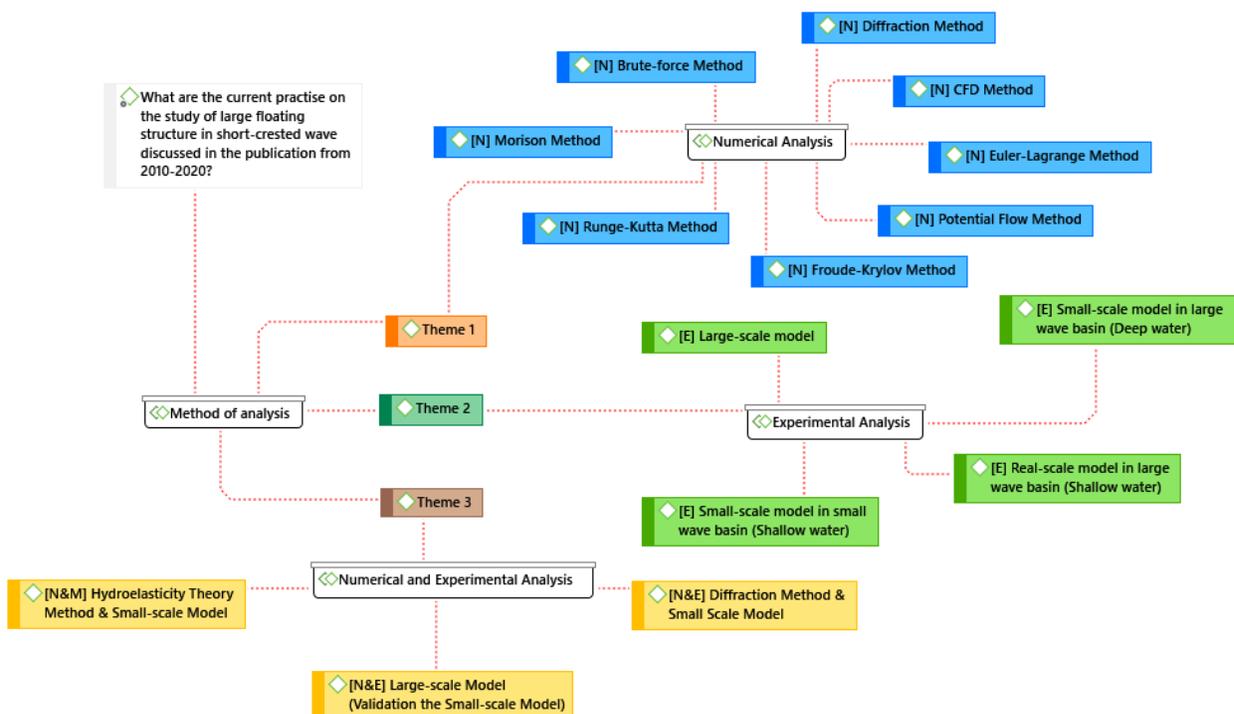| Category	Type										Total
Experimental Analysis	CS			1	1		1				7
	SSC	1									
	S									1	
	TS		1								
	WEC					1					
Numerical and Experimental Analysis	SSC				1						3
	TS				1						
	S									1	
Type of floating structure	**B** = Barge **CS** = Classic SPAR **FSS** = FPSO (ship-shape) **HLV** = Heavy-lift Vessel **SSC** = Semi-submersible (six-circular column					**SS** = Semi-submersible (symmetrical) **S** = Ship **TS** = Truss SPAR **WEC** = Wave Energy Converter					

4. QUALITATIVE ANALYSIS

Figure 4: A network outlook on how research questions can be addressed by thematic review.

Figure 4 shows a network view on how to answer the research question through the thematic review, which is as follows:

What are the current practices on studying large floating structures in short-crested waves discussed in publications from 2010 to 2020?
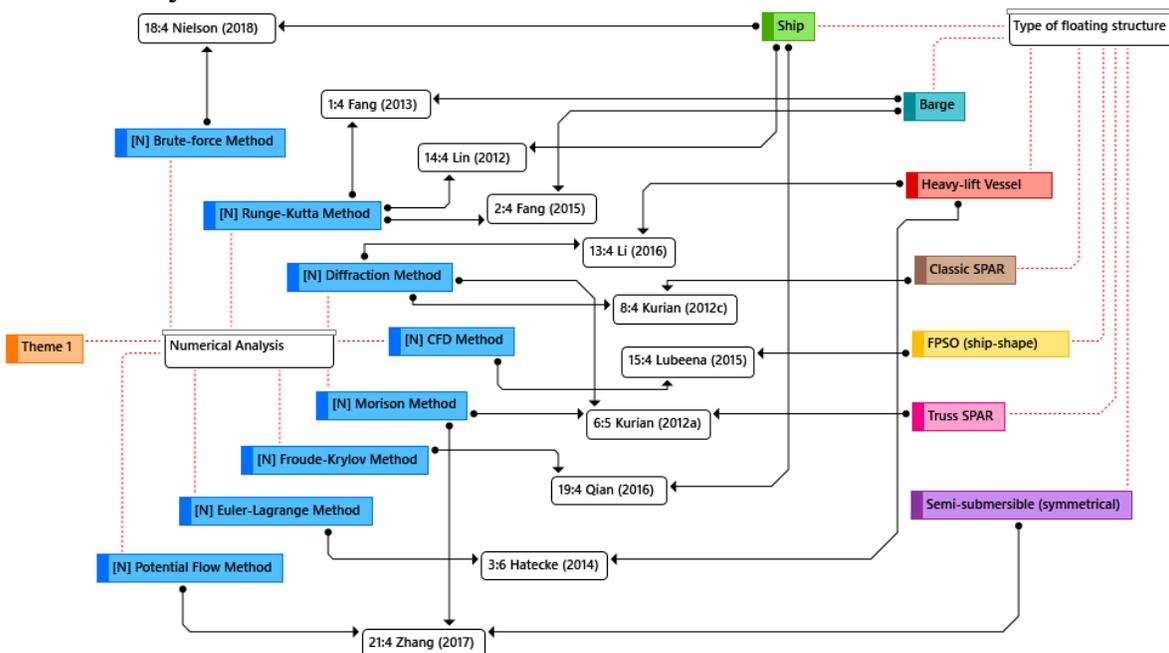
4.1 Numerical analysis

Figure 5: A network view on the numerical analysis of large floating structures in short-crested waves.

Numerical analysis is concerned with the derivation, definition, and study of methods of mathematical numerical solutions [18]. Numerical analysis is a famous method due to less time consumption and almost zero cost. Figure 5 shows a network view of the numerical analysis method used to study the hydrodynamic response of large floating structures in short-crested waves. [19] used the brute-force analysis method to study the response of waves and ships in short-crested waves. At the same time, [20] and [21] looked at the hydrodynamic response of vessels using the Runge-Kutta and Froude-Krylov analysis methods. The Runge-Kutta analysis method was also used by [22] and [23]on a barge to analyze the hydrodynamic response in short-crested waves. The diffraction analysis method seems to be popular in short-crested wave analysis of large floating structures, which was used by [24], [25], and [26] to study truss SPAR, classic SPAR, and heavy-lift vessel respectively. Hatecke et al. (2014) also studied the behavior of heavy-lift ships due to the short-crested wave effect, but they used the Euler-Lagrange method. Some of the researchers used a combination of two different numerical analyses in their study. For example, using a variety of diffraction and Morison equation methods in studying the truss SPAR analysis [25]. [27] also applied a combination of potential flow theory and Morison equation method on the symmetrical semi-submersible analysis. The computational fluid method (CFD), commonly used in dynamic analysis, is not standard for analyzing floating structures in short-crested waves.
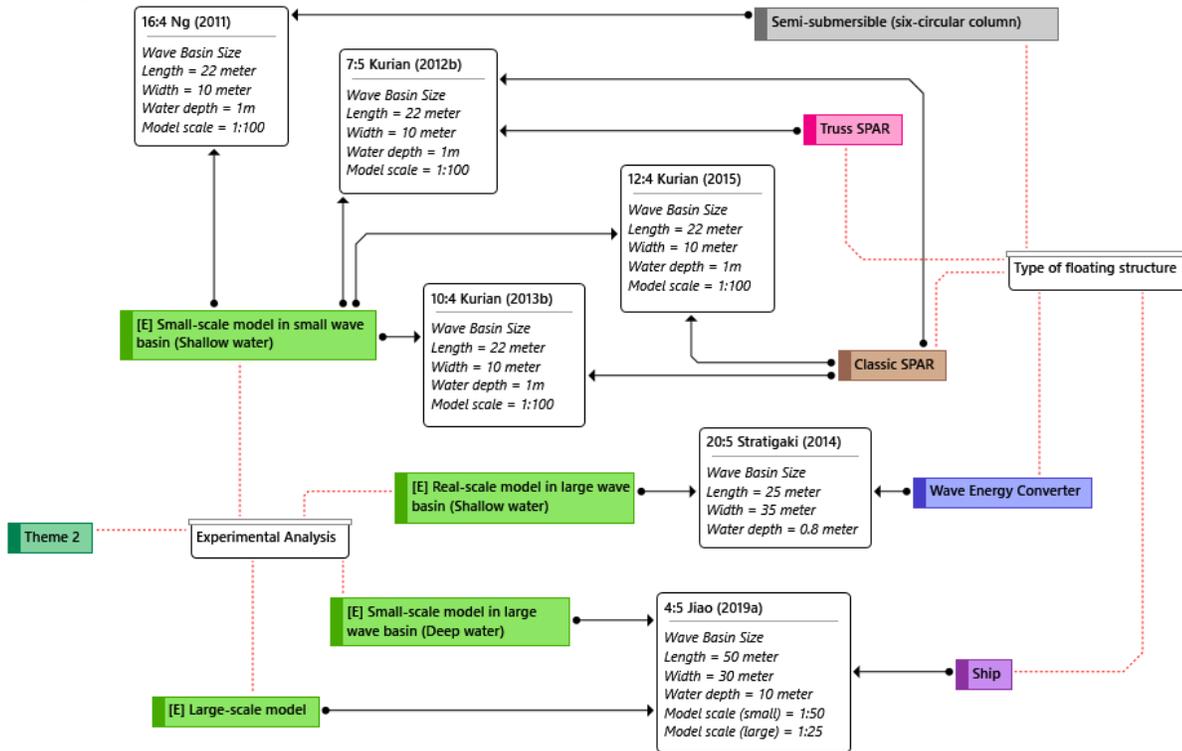
4.2 Experimental Analysis

Figure 6: A network view on the experimental analysis of large floating structures in short-crested waves.

Experimental analysis in the study of hydrodynamic behavior of a large floating structure is often conducted in a wave basin. Although exploratory analysis is the best approach in hydrodynamic analysis, it is less popular than numerical analysis due to time, cost, and difficulty. The challenge faced in the experimental analysis is the availability of large and deep-water basins with snake-type wavemakers that can generate short-crested waves. The empirical analysis of hydrodynamic response usually involves small-scale, large-scale, and real-scale analyses. [28], [25],[29], and [30] ran a small-scale ratio of 1:100 physical model testing of classic SPAR, truss SPAR, and a six-circular column semi-submersible in a small wave basin with dimensions of 22 m in length, 10 m in width, and only 1 m in depth. [31] studied the experimental analysis of a large energy converter in a real model scale in a giant wave basin of shallow water, with dimensions of 25 m in length, 35 m in width, and 0.8 m in water depth. Recently, [14] studied the ship motion comprehensive using small-scale and large-scale physical model testing in a giant wave basin (50-m length, 30-m width, and 10-m depth). Then, the small-scale ratio of 1:50 and the large scale ratio of 1:25 of a ship was tested under short-crested waves in a giant wave basin and real-sea conditions.
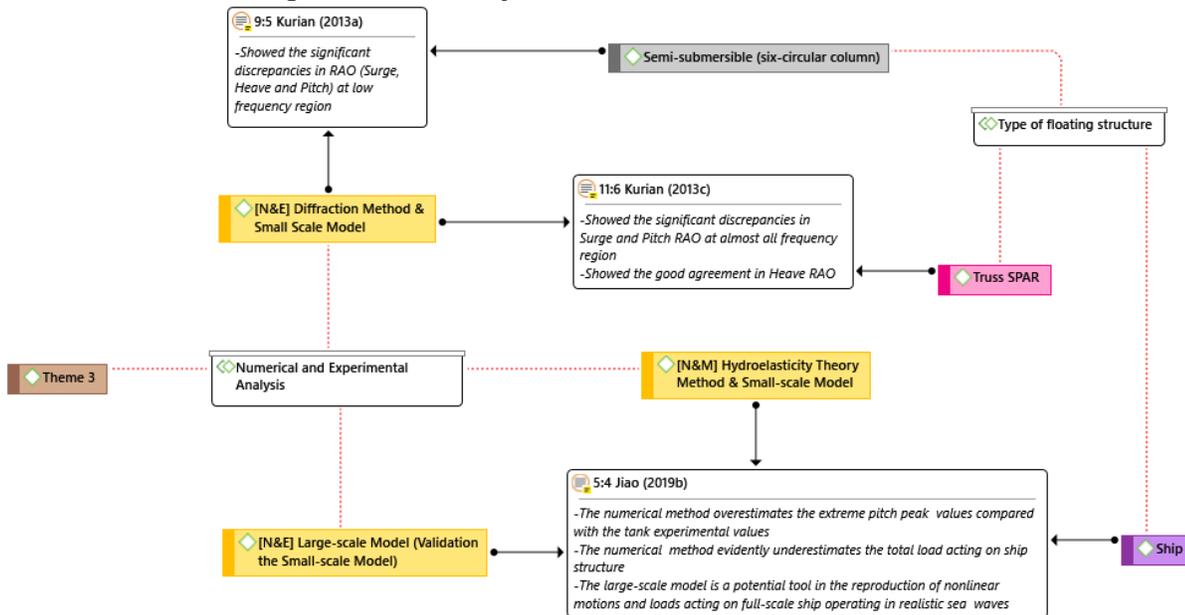
4.3 Numerical and Experimental Analysis

Figure 7: A network view on large floating structures' numerical and experimental analysis in short-crested waves.

The combination of numerical and experimental analysis has usually been used to validate the numerical analysis. Figure 3.5 shows a network of numerical and small-scale experimental analyses of large floating structures in short-crested waves. [28] [29] analyzed a six-circular column semi-submersible and a truss SPAR floating platform using the diffraction theory and experimental analysis methods. Even the results showed discrepancies in some frequency regions between the numerical and experimental analyses. It is contributed to a significant finding in their study. A combination of hydro elasticity theory and a small-scale experimental method was used by [14] to investigate the hydrodynamic response of a ship in short-crested waves. Furthermore, to validate the small-scale experimental analysis,[14] conducted a large-scale experimental analysis in actual sea conditions with a scale factor of 1:25. Although it seems to have high-cost consumption, the result of their study is highly worthwhile.

5. CONCLUSION

This paper highlighted a conventional approach in the current hydrodynamic analysis of large floating structures in short-crested waves through numerical analysis, experimental analysis, and a combination of numerical and empirical research. Despite implementing a numerical method in the hydrodynamic analysis of large floating structures in short-crested waves, several issues were discovered. Some elements include the absence of parameters to distinguish the mean or peak of short-crested waves and no relationship between motion amplitude and maximum wave crested to develop a precise numerical analysis. Moreover, the experimental study lacks fully developed wind waves because they need enough space and more time and cost. Although some worldwide wave basin equipment allows short-crested irregular waves to be generated, the 3D waves produced artificially in the wave basin differ from those made in actual sea conditions with short wind waves. Large-scale model experiments have been built with high-cost consumption in real sea conditions to address the limitations attributed to conventional tank test methods.

From the trend in the previous publication, the combination of numerical and experimental analysis is not popular. Still, various analysis methods are effective, worthwhile, and meaningful, especially in actual sea conditions.

Nonetheless, the laboratory tank test has apparent benefits, such as a well-controlled environment and cost-saving in testing. Future research should investigate how the combination of various types of analysis methods to investigate the hydrodynamic response of large floating structures can be executed in short-crested waves. Comprehensive study and analysis can solve real problems by analyzing the hydrodynamic analysis of large floating structures in short-crested waves.

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