SUSTAINABLE
CIVIL INFRASTRUCTURE DEVELOPMENT:
CASE STUDIES

(Second Edition)

Edited by

SUDIP BASACK
GHRITARTHA GOSWAMI
JOYDEEP DUTTA
M K LOGANATHAN

Sustainable Civil Infrastructure Development: Case Studies

Edited by

Sudip Basack
Principal
Regent Education and Research Foundation
Affiliated: MAKA University of Technology
Kolkata 700113, India.
and
Adjunct Professor of Civil Engineering
Graphic Era Deemed to be University
Dehradun, India.

Ghritartha Goswami
Research Associate
North Eastern Regional Institute of Science & Technology
Nirjuli 791109, Arunachal Pradesh, India.

Joydeep Dutta
Superintending Engineer
Assam Water Centre, External Aided Projects
Water Resources Department
Government of Assam
Guwahati, Assam, India.

M. K. Loganathan
Principal & Professor
Gyan Vihar School of Engineering & Technology
Suresh Gyan Vihar University
Jaipur, India.

Second Edition

Iterative International Publishers
IIP

Title of the Book: Sustainable Civil Infrastructure Development: Case Studies

Second Edition: 2024, IIP Series

Disclaimer
The authors are solely responsible for the contents published in this book. The publisher or editors do not take any responsibility for the same in any manner. Errors, if any, are purely unintentional and readers are requested to communicate such errors to the editors or publishers to avoid discrepancies in future.

ISBN: 978-93-6252-138-5

MRP: 1,710/-

Publisher, Printer & Distributor:
Selfypage Developers Pvt. Ltd.,
Pushpagiri Complex,
Beside SBI Housing Board,
K.M. Road Chikkamagaluru, Karnataka.
Tel.: +91-8861518868
E-mail: info@iipseries.org

IMPRINT: IIP Iterative International Publishers

For Sales Enquiries
Contact: 91- 8861511583
E-mail: sales@iipbooks.com

ISBN: 978-93-6252-138-5

Chapter 25

Hydrodynamic Response of an Offshore Floating Wind-Solar-Aquaculture System

Basu Bhowmick
Undergraduate student
Department of Civil Engineering
Dr. B.C. Roy Engineering College, Durgapur, India.
Corresponding author's email: shovan.roy@bcrec.ac.in

Timir Kanti Konar
Undergraduate student
Department of Civil Engineering
Dr. B.C. Roy Engineering College, Durgapur, India.

Shovan Roy
Assistant Professor
Department of Civil Engineering
Dr. B.C. Roy Engineering College, Durgapur, India.

Koyndrik Bhattacharjee
Assistant Professor
Department of Civil Engineering
Dr. B.C. Roy Engineering College, Durgapur, India.

Chanchal Das
Assistant Professor
Department of Civil Engineering
Dr. B.C. Roy Engineering College, Durgapur, India.

Abstract

This study presents a new concept design combining a solar array with a floating steel fish-farming cage. This combined solar and aquaculture system is intended to utilize the ocean space and water resources more effectively and more economically, while greatly shortening the payback period of investment in offshore power generation. The details of this solar and aquaculture design are described, showing that a square-shaped fishing cage serves as a floating foundation for the 7600 m^2 solar array. ANSYS Design Modeler and Aqwa are used to perform the hydrodynamic response analysis of free-floating condition of solar and aquaculture in the time domain and frequency domain and coupled analysis involving solar and aquaculture and the mooring lines in the frequency domain and time domain. The motion RAOs indicated that the proposed concept possesses effective hydrodynamic seakeeping performances. A potential site located in the Bay of Bengal is selected to deploy the solar and aquaculture system. Its feasibility is then examined in terms of the hydrodynamic motions and structural dynamic response driven by waves and current. Fully coupled time-domain simulations are carried out for 50-year survival conditions. The whole structure exhibits outstanding performance for its small motions in random seas. Technically, the solar and aquaculture system has strong competitiveness and wide prospects in the offshore industry for both power exploitation and marine aquaculture in intermediate and deep waters.

Keywords: Floating foundation; Offshore fish farming; Combined solar-aquaculture system; Hydrodynamic analysis and Responses

I. Introduction

This study is focused on the hydrodynamic analysis for a Wind Solar Aquaculture (WSA) offshore structure shown in Figure 25.1); which are being used in blue economy for support economy of a country.

The WSA structure operation are secured to use of mooring line. The moored system of a structure made the study of hydrodynamic response. For renewable energy like wind, solar the structure should be a special and cutting edge system and the structure should combine with net steel cage that is helpful for fish farming.

This floating platform support the economy like a foundation support a building, which also includes solar, wind energy systems and fish farming space. This platform is fixed under the sea ground surface and electricity will be produced by the vertical axis wind turbines (VAWTs) and by the solar panels. The power should help the structure to run aquaculture system. Fish farming cage in this cage make this structure economical structure. WSA structure is involved for blue economy, blue economy means the sustainable use of ocean resources for economic growth of a country that will help to improve livelihoods, employment related to this ocean eco system. It encompasses to the tourism industry, renewable energy industry and also help in educational sector like ocean engineering, biotechnology etc. students. The aim of blue economy to balance economic development and protect the environment.

In this study we have studied a novel concept of combines multiple megawatt VAWTs and solar panel with a floating aquaculture steel fish cage. The solar panel take more than 7000 m^2 and the panel is installed top of the cage. The whole WSA system is designed unconditionally stable with the Centre of gravity and Centre of buoyancy. In hydrodynamic analysis for accounting wave actions the Morison formula applied. As a case study, a potential offshore site location in extreme south east direction of India and Bay of Bengal. The extreme responses under a 50year wave and wind condition are investigated using software ANSYS (v 17.1). Aquaculture ecosystem refers to the cultivation of aquatic organisms such as fish, shell fish in a controlled environment. The use of ANSYS can help us to design and hydrodynamic analysis of aquaculture fish cage. In aquaculture system floating structure is an essential component. In addition mooring secured floating structure is simultaneously determine results tension, bending, stiffness is determining by ANSYS.

II. The WSA Concept

In the below figure, the WSA concept is clear to comprises main five parts;

1. A steel cage.
2. Four vertical axis wind turbine mounted at the top of the cage.
3. A group of solar panel to capturing solar energy.
4. Mooring systems those stabilized the structure.
5. Quarters for workers. (optional)

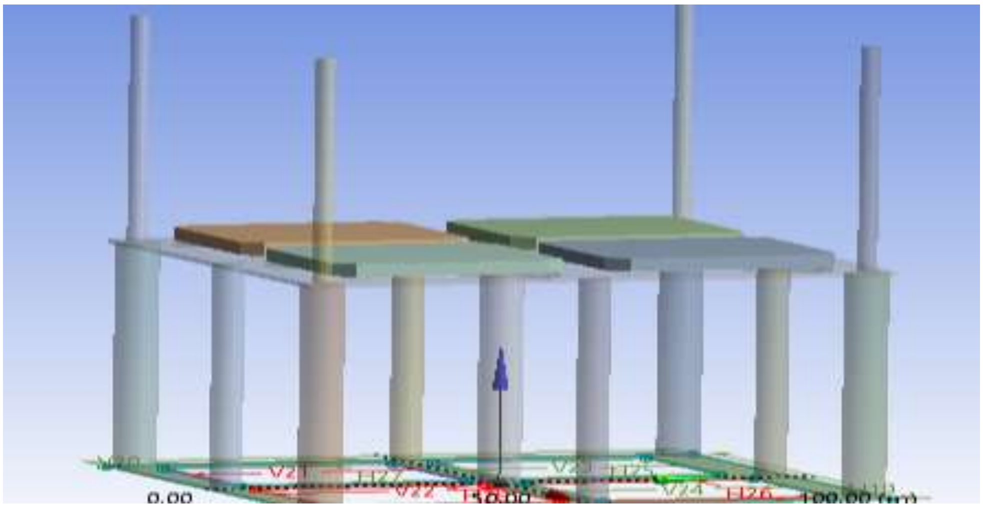

Figure 25.1: Wind Solar Aquaculture (WSA) offshore structure

This WSA structure occupy less marine area and this is more economically. The estimated volume of WSA structure more than 250000 m^3. This economical system revenue multi begger rupees from production. The heavy investment in offshore wind power generation can be greatly reduce to several years. In turn, the power generated by the wind-solar system easily satisfies the electricity consumption by fishery.

III. Numerical Model of WSA Structure

Steel Fishing Cage

In this structure Steel cage is considered a very important role. Whole structure consist of columns (shown in Table 25.1), steel cage and steel deck. Breadth of structure is 93.566m. In the steel deck four openings are there breadth is 36.461m and thickness of the deck is 0.500m.

Table 25.1: Column details

Member	Properties	Area(m2)	Quantity	Total area(m2)
Corner column	D=6.8m, r= 3.4m, h= 60m.	$2\pi 3.4 * 60 + 2\pi 3.4^2 = 1354.4$	4	$4 * 1354.4 = 5417.6$
Centre column	D=6.0m, r=3.0m, h=60m.	$2\pi 3.0 * 60 + 2\pi 3.0^2 = 1186.92$	1	$1 * 1186.92 = 1186.92$
Side column	D=5.0m, r=2.5m, h=60m	$2\pi 2.5 * 60 + 2\pi 2.5^2 = 981.74$	4	$4 * 981.74 = 3926.96$

Mooring Systems

The WSA is keeping station that's maintained and controlled by mooring line. In this structure definition we need 3 mooring line for one connection point. We have 4 connection point so we need 12 mooring line. The connection points (end point of structure) is under the water. The distance between C.G. and C.B. the station keeping mooring systems. In this analytical project we have study about the catenary connection such as like cable connection that used as mooring line in this project.

1. The natural period of motion and makes are significantly cut short by tension in mooring lines. The floater more susceptible to wave-frequency loads.

2. In our project study we have considered WSA will be transported where the water depth is 100-200m, where mooring line affected by tidal waves variations.
3. Utilizing polyester line is more expensive than using catenary connections (mooring line) in the same water depth.

As shown in figure 12 identical catenary lines are deployed and used to mooring line in the WSA system. There are 12 symmetrical mooring line in mooring system. Symmetrically in a circle around the fishing cage, in accordance with the DNVGL – OS – E301 design guidelines. In each corner column has one connection point. Connection point is a point where the 3 mooring lines from 3 fixed point are connect in one connection point. The angular distance between two mooring line is 5° . The design parameters of mooring line given in the Table 2 and mooring line configuration shown in Figure 25.2.

Table 25.2: Design parameters of mooring line

Segment	Length(m)	Diameter(m)	Mass density(kg/m)	Break load(kN)	Characteristic strength (kN)
Upper line	135	0.115	82.0	3965	3766
Lower line	507	0.115	82.0	3965	3766
Clump Mass	8	0.930	11.666	-	-

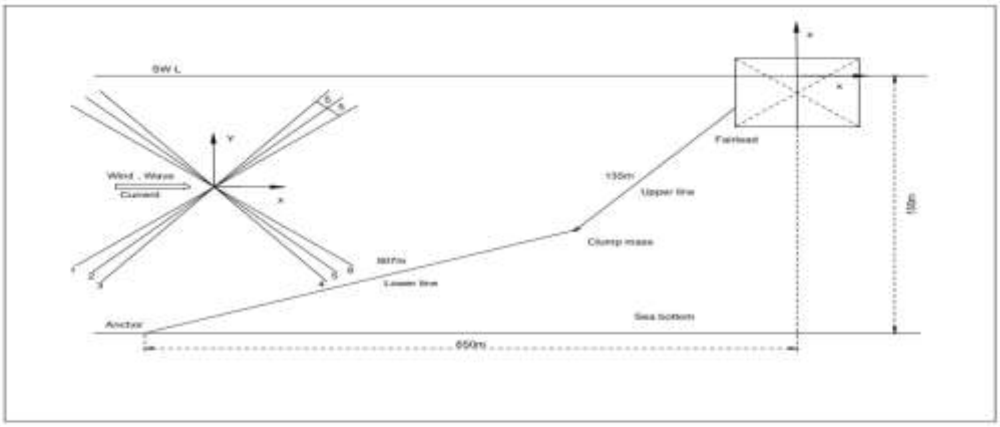

Figure 25.2: Mooring line configuration

Mesh

Meshing is also known as mesh generation, it is the process to divide a structure to limited number of elements and number of nodes (shown in Figure 25.3).

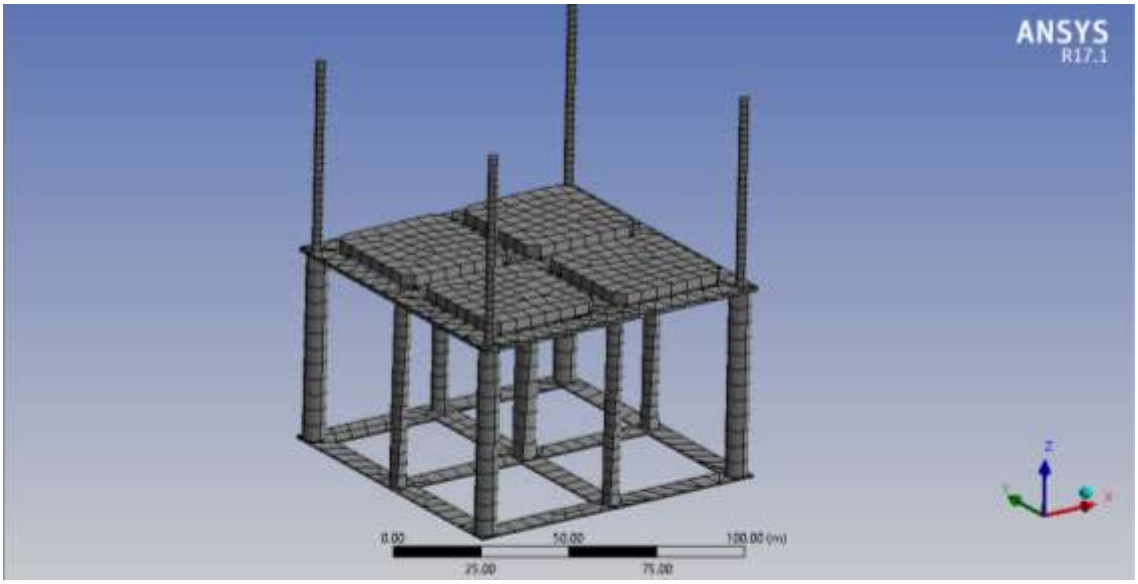

Figure 25.3: Meshing of WSA

Details of Mesh	
Defaults	
Global Control	Basic Controls
Mesh Parameters	
Defeaturing Tolerance	4 m
Maximum Element Size	10 m
Maximum Allowed Frequency	0.149 Hz (Estimated from in...
Meshing Type	Program Controlled
Generated Mesh Information	
Number of Nodes	10206
Number of Elements	2344
Number of Diffracting Nodes	0
Number of Diffracting Elements	0

Figure 25.4: Details of meshing in ANSYS AQWA

IV. Results

Hydrostatic analysis of WSA

The hydrostatic analysis of this WSA will occur on the structure equilibrium position, where the point of buoyancy balance overall the WSA system included

ISBN: 978-93-6252-138-5

mooring systems. The relevant parameters of hydrostatic analysis is given point of mass where center of gravity works and point of buoyancy where center of buoyancy works also include connection point.

In WSA the point mass below the point of buoyancy, which means that the whole system is unconditionally stable like spar type platform.

Hydrostatic Results						
Structure		WSA				
Hydrostatic Stiffness						
Centre of Gravity (CoG) Position:	X:	0. m	Y:	0. m	Z:	-40.73 m
		Z		RX		RY
Heave (Z):		0. N/m		0. N/°		0. N/°
Roll (RX):		0. N.m/m		1.9824e10 N.m/°		0. N.m/°
Pitch (RY):		0. N.m/m		0. N.m/°		1.9824e10 N.m/°
Hydrostatic Displacement Properties						
Actual Volumetric Displacement:		25110244 m^3				
Equivalent Volumetric Displacement:		16099.512 m^3				
Centre of Buoyancy (CoB) Position:	X:	0. m	Y:	0. m	Z:	-36.23 m
Out of Balance Forces/Weight:	FX:	0.	FY:	0.	FZ:	1558.6897
Out of Balance Moments/Weight:	MX:	0. m	MY:	0. m	MZ:	0. m
Cut Water Plane Properties						
Cut Water Plane Area:		0. m^2				
Centre of Floatation:	X:	0. m	Y:	0. m		
Principal 2nd Moment of Area:	X:	0. m^4	Y:	0. m^4		
Angle Principal Axis makes with X(FRA):		0.°				
Small Angle Stability Parameters						
CoG to CoB (BG):		-4.5 m				
Metacentric Heights (GMX/GMY):		4.5 m		4.5 m		
CoB to Metacentre (BMX/BMY):		0. m		0. m		
Restoring Moments about Principal Axes (MX/MY):		1.9824e10 N.m/°		1.9824e10 N.m/°		

Figure 25.5: Hydrostatic analysis result of WSA;

Stability analysis

The forgoing stability analysis of this WSA system there is six degree of freedom for response different type of inputs. The freedom point is Surge, Sway, Heave, Pitch, Roll, and Yaw. The responses is given below; in this analysis of six degree of freedom we found every modes have a crucial degree of freedom. The movement of effected points are given below (shown in Figure 25.6).

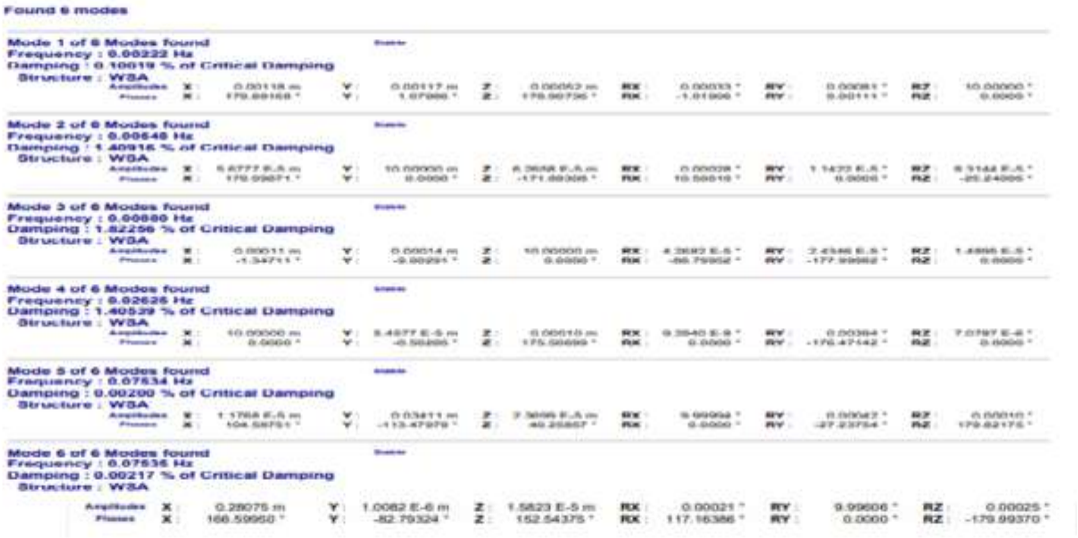

Figure 25.6: Natural frequency of six degree of freedom

Mode 1- RZ: 10.000°, Mode 2- Y: 10.00000m, Mode 3- Z: 10.00000m, Mode 4- X: 10.00000m, Mode 5- RX: 9.99994°, Mode 6-RY: 9.99606°.

In the analysis process of WSA structure; the structure will be response in two degree of freedom out of six degree of freedom. The most effected position is Heave (Z) and Yaw (RZ). But in Z direction the structure response more than RZ direction.

Z Direction Iteration Step

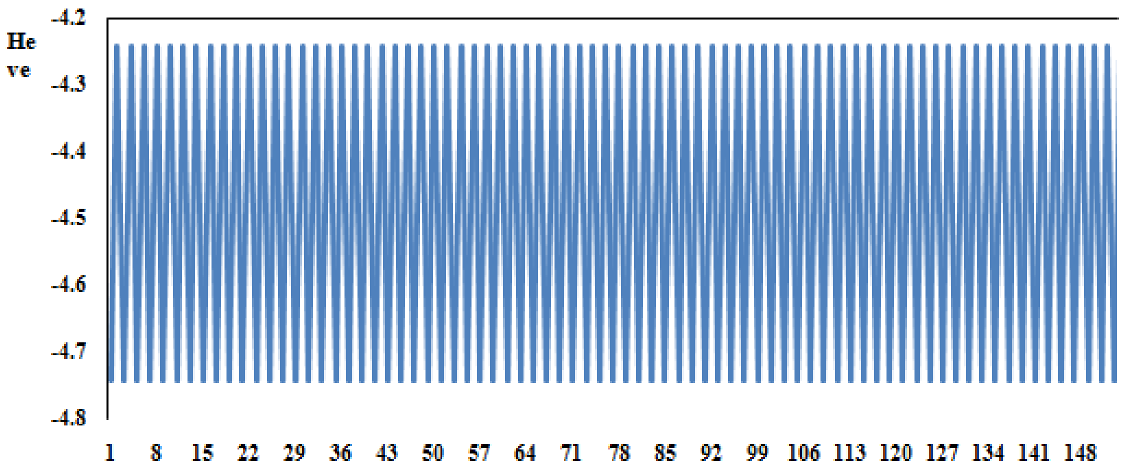

Figure 25.7: Stability Analysis in Z Direction

It involves the studying the response of the WSA Structure and a particular wave spectrum. And this spectrum is commonly used to characterized wind generated waves and its significant wave height and wave period. On analysis time we have focused on vertical movement of the structure by pierson-moskowitz wave type. The graph and table are showing six months data (shown in Figure 25.7 and 25.8).

Name	Structure Position, Actual Response
State	Not Solved
Details of Structure Position, Actual Response	
Presentation Method	Line
Axes Selection	Distance/Rotation vs beration Step
Line A	
Structure	WSA
Type	Structure Position
Sub Type	Actual Response
Component	Global Z
Reference Point	Centre of Gravity (WSA)
Motion Relative To	Origin of Fixed Reference Axes (FRA)
Abscissa Position of Minimum	0.0
Abscissa Position of Maximum	0.0
Minimum Value	0.0m
Maximum Value	0.0m
Line B	
Structure	Undefined...

Figure 25.8: Details of Stability Analysis in Z Direction

RZ Direction

It involve in this response study on the structure the wave action generated by rotational direction. We have learn about this study how the structure response on rotational movement caused by pierson-moskowitz wave type. The graph and table are showing six month data (shown in Figure. 25.9 and 25.10).

Iteration Step

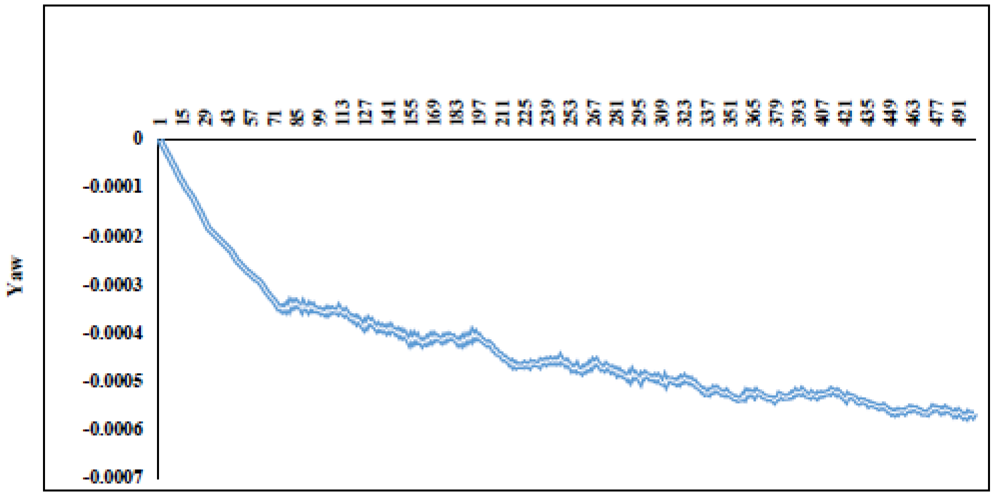

Figure 25.9: Stability Analysis in RZ Direction

Name	*Structure Position, Actual* Response
State	Not Solved
Details of Structure Position, Actual Response	
Presentation Method	Line
Axes Selection	Distance/Rotation vs lteration Step
Line A	
Structure	WSA
Type	Structure Position
Sub Type	Actual Response
Component	Global Z
Reference Point	Centre of Gravity (WSA)
Abscissa Position of Minimum	0.0
Abscissa Position of Maximum	0.0
Minimum Value	0.0”
Maximum Value	0.0”
Line B	
Structure	Undefined...

Figure 25.10: Details of Stability Analysis in RZ Direction

ISBN: 978-93-6252-138-5

Hydrodynamic Analysis of WSA

Time Response Analysis with Pierson-Moskowitz

In the analysis process of WSA structure; the structure will be response in two degree of freedom out of six degree of freedom. The most effected position is Surge (X), Sway (Y), Heave (Z), Roll (RX), Pitch (RY) and Yaw (RZ). Here the WSA structure response different with time. In the below all graph are shown.

X Direction

Time response analysis by Pierson Moskowitz in x direction involve studying how a WSA structure response to the movement direction by wave Pierson Moskowitz. The analysis in surge direction is crucial for determining the safe and reliable operation of offshore structure and other marine structure (shown in Figure 25.11).

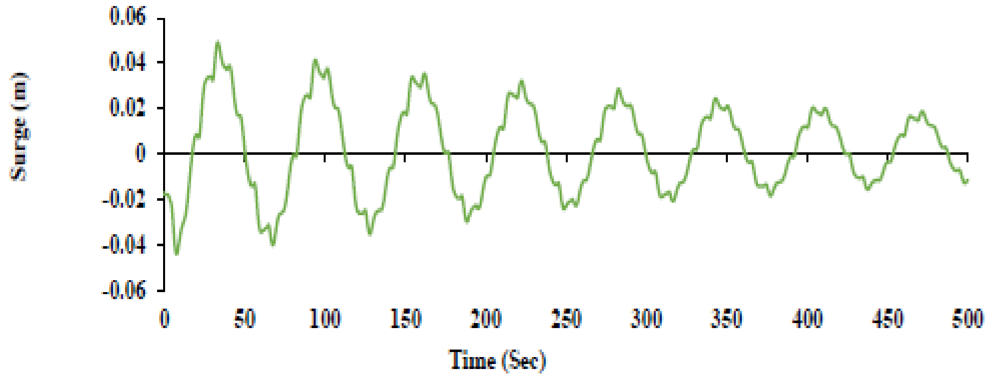

Figure 25.11: Time Domain Response in X Direction

Y Direction

Time response analysis by Pierson Moskowitz in Y direction involve studying how a WSA structure response to the movement direction by wave Pierson Moskowitz. This analysis is an important tool for understanding and predicting the dynamic behavior of the structure (shown in Figure 25.12)

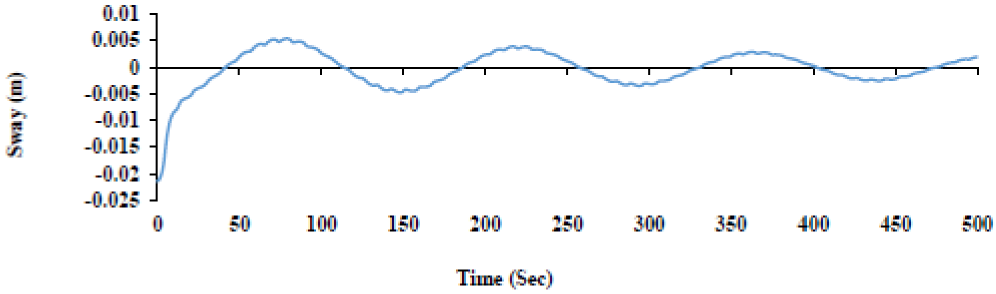

Figure 25.12: Time Domain Response in Y Direction

Z Direction

In this analysis similar to surge direction analysis. In this analysis focused on understanding how this WSA structure react vertically movement by pierson moskowitz wave (shown in Figure 25.13).

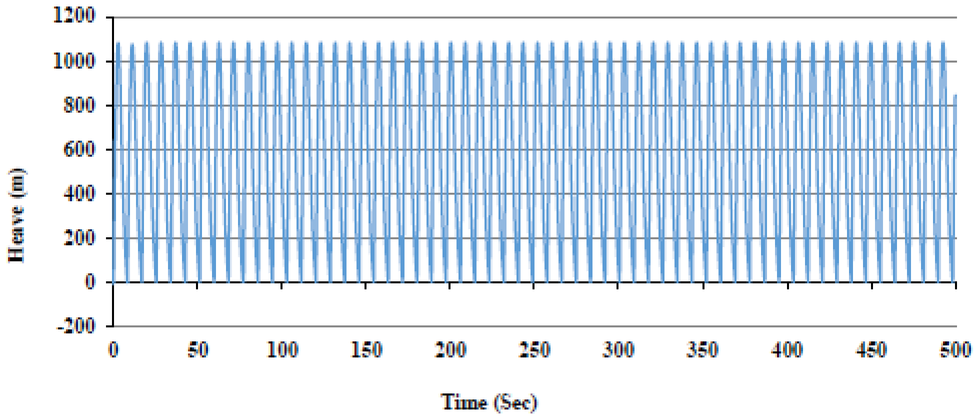

Figure 25.13: Time Domain Response in Z Direction

RX Direction

In this analysis we have to study the structure rotation about x direction and dynamically its behavior about movement due to wave spectrum (shown in Figure 25.14).

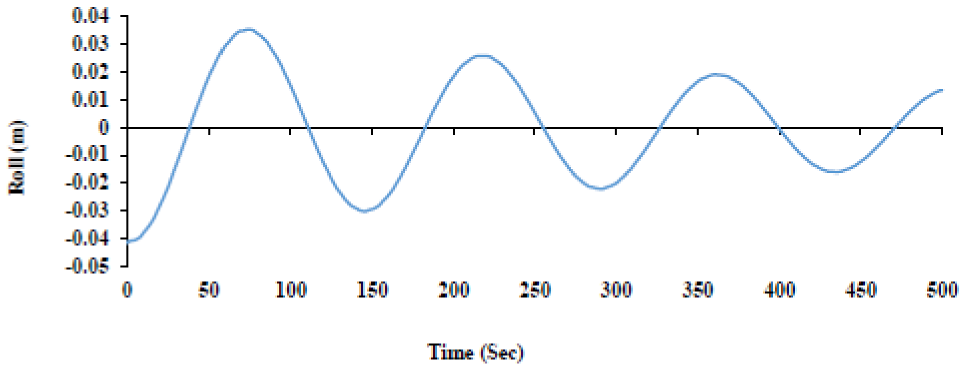

Figure 25.14: Time Domain Response in RX Direction

RY Direction

The response of the structure in RY direction would be analyzing the motion and loading characteristics over the period of time and analysis rotation about y direction. This numerical techniques used to calculate dynamic response of the marine system (shown in Figure 15).

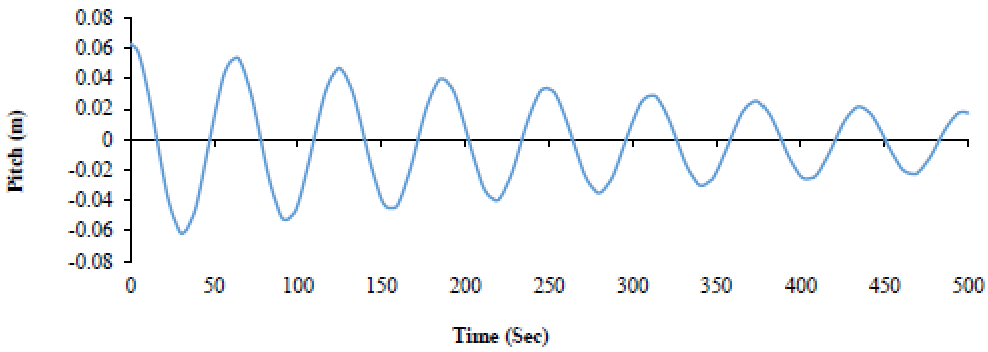

Figure 25.15: Time Domain Response in RY Direction

RZ Direction

The response of the structure in RZ direction would be analyzing the motion and loading characteristics over the period of time and analysis rotation about Z direction. This numerical techniques used to calculate dynamic response of the marine system (shown in Figure 25.16).

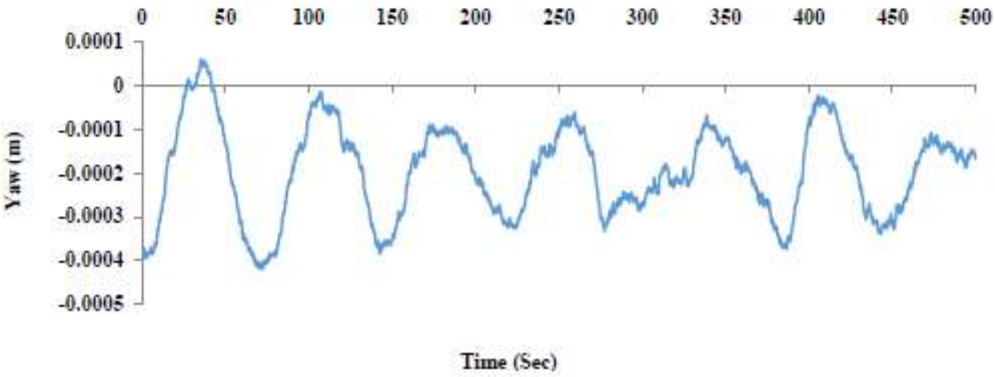

Figure 25.16: Time Domain Response in RZ Direction

V. Conclusion

The design and assessment of offshore structures in the oil and gas industry necessitate a thorough understanding of their response to static and dynamic loading conditions. This study presents a comprehensive analysis of an offshore structure, employing both static and dynamic analytical approaches to ensure structural integrity and performance across diverse environmental scenarios.in the static analysis phase, finite element analysis technique are utilized to evaluate the structure’s response to steady-state loading, including gravitational, wind, and wave forces. This investigation assesses stress distribution, deformation patterns, and load carrying capacity. The results provide critical insights into the structure’s stability and safety under static loading conditions, offering a foundation for robust design and operational consideration. Similarly to stability analysis in different directions that analysis natural frequency of the structure.

VI. References

[1] Xiangyuan Zheng; Huadong Zheng; Yi Lei; Wei Lei. 2020. An Offshore Floating Wind-Solar-Aquaculture System: Concept Design and Extream Response in Survival Condition. MDPI.
[2] Yunil Chu; C.M. Wang. 2020. Hydrodynamic Response Analysis of Combined Spar Wind Turbine and Fish Cage for Offshore fish Farms. ResearchGate.
[3] Yuting Zhai; Haisheng Zhao; Xin Li; and Wei Shi. 2022. Hydrodynamic Responses of a Barge-Type Floating Offshore Wind Turbine Integrated with an Aquaculture Cage. MDPI.
[4] Beveridge, M.C.M., 2004. Cage Aquaculture, 3rd edition. Blackwell Publishing, Oxford.
[5] Chu, Y. I., Wang, C. M., Park, J. C., and Lader, P. F., 2020. Review of cage and containment tank designs for offshore fish farming. Aquaculture, 734928.
[6] Chu, Y. I., and Wang, C. M., 2020. Combined spar and partially porous wall fish cage for offshore site. Proceedings at the 16th East Asia-Pacific Conference on Structural Engineering & Construction, December 3-6, 2019, Brisbane, Australia

Authors Biography

Basu Bhowmick is an undergraduate student in department of civil engineering from Dr. B. C. Roy Engineering College, Durgapur, West Bengal (2020-2024 Batch).

Timir Kanti Koner is an undergraduate student in department of civil engineering from Dr. B. C. Roy Engineering College, Durgapur, West Bengal (2020-2024 Batch).

Dr. Shovan Roy is a B.Tech in Civil Engineering from Sri Ramdeobaba Kamla Nehru Engineering College and M.Tech in Geotechnical Engineering from North Eastern Regional Institute of Science & Technology (NERIST). Since August 2014 he has been working as Assistant Professor at Dr. B. C. Roy Engineering College, Durgapur, West Bengal. He is having almost 11 years of teaching experience His areas of interests are Geotechnical Engineering and Floating Offshore structures.

Koyndrik Bhattacharjee is a B.Tech in Civil Engineering from N.I.T. Durgapur and an M.Tech in N.I.T. Durgapur itself. Since July, 2018 he is working as Assistant Professor at Dr. B.C Roy Engineering College, Durgapur, West Bengal. He has more than five years of teaching experience. His areas of interest are Structural Design, Structural Dynamics, Earthquake.

Chanchal Das is a B.Tech in Civil Engineering from B.I.E.T., Suri and an M.E. in Structural Engineering from Bengal Engineering and Science University, Shibpur. Since January, 2015 he is working as Assistant Professor at Dr. B. C. Roy Engineering College, Durgapur, West Bengal. He is having almost twelve years of teaching experience. His areas of interests are Structural and Materials Engineering, Geotechnical Engineering and Pavement Design.

ABOUT THE EDITORS

Sudip Basack, PhD, FIE, CEng, MASCE is a civil engineering professional with significant academic experience at responsible senior positions in India and abroad. He published more than 125 technical papers in reputed journals and conferences and is recipient of several research awards at national and international levels. He is an active reviewer of numerous top-class international journals. He has supervised more than 10 research students at postgraduate (Masters and PhD) levels and executed sponsored research projects in different Universities. He has undertaken several academic visits in many countries including USA, UK, Germany, Australia, New Zealand, Singapore, China, etc

Ghritartha Goswami, MTech, AMIE, CEng, Aff.MASCE. Is a professional civil and water resources engineer, currently a Ph.D. scholar at NERIST, Arunachal Pradesh, India. Formerly an Assistant Professor in civil engineering at Scholars' Institute of Technology and Management, Guwahati, Assam, India. He has published more than thirty papers in different reputed international and national journals and supervised 5 graduate-level research projects. He is an active reviewer of numerous top-class international journals. He has been invited as keynote speaker in many countries, including China, Mexico, etc. For his remarkable accomplishments in his profession, he was recently named a Young Scientist by the International Scientist Awards.

Joydeep Dutta, MTech, MIE, AES is a professional civil engineer currently Superintending Engineer, Government of Assam Guwahati, INDIA. He has vast industrial experience of about 30 years. He graduated in civil engineering from North Eastern Regional Institute of Science and Technology. He has done his post-graduation in water resources from Indian Institute of Technology, Roorkee, India, in the year 2005. Currently, he is a PhD researcher at Northeast Regional Institute of Science and Technology, Government of India. He has published several research papers at national and international levels.

M K Loganathan has been awarded a PhD from Indian Institute of Technology, Delhi, India and undertook Post-Doctoral research from Chang Gung University, Taiwan. He has significant experience in senior positions, both in the industry and academics. He has remarkable research contributions, including sponsored research funding & industrial consultation, peer reviewed publications, supervising Master and Doctoral students, etc. His areas of research include reliability and maintenance of infrastructure, renewable energy, coastal environment, among others.

ISBN: 978-93-6252-138-5

MRP Rs. 1, 710/-

Selfypage Developers Pvt. Ltd