Arab Academy for Science, Technology, and Maritime Transport

The International Maritime and Logistics Conference “**Marlog 12**”
Innovative Technologies for Ports and Logistics
Towards a Sustainable Resilient Future”
12 – 14 March 2023

FUTURE PROOF INFRASTRUCTURE FOR PORT-CITY: CASE STUDY FOR THE SUSTAINABILITY OF SUEZ CANAL ENTRANCE GROINS AGAINST FUTURE EXTREME WAVE CONDITIONS

Mohamed M. Abouelnasr (1)

(1) Arab Academy for Science, Technology & Maritime Transport, Alexandria, Egypt,
M.Abouelnasr5432@student.aast.edu

ABSTRACT: In line with market needs, ports should adopt green-port policies that integrate social, economic, and environmental factors. Several coastal international organizations are spreading awareness of maritime market needs for Sustainability Development Goals (SDGs). Resilience infrastructure of cruise tourism ports is one of the key cornerstones for future-proof port-city infrastructure. In port-city coastal projects, each port is a city. Ports integrate markets and provide services, creating economic benefits. Port-cities are economically important marine hubs, they connect the local and global.

The article aims to study the future proof infrastructure for port-city using a case study for the sustainability of entrance groins of Suez Canal against future extreme wave conditions. As sustainable development boosts port performance. Coastal planning prioritizes sustainability as the rapid growth of the global market has caused a socioeconomic development-environmental asset mismatch, creating major social, economic, and environmental dangers. Sustainable development meets requirements without compromising Earth's capacity to meet future needs. SDGs are the best strategy to decrease port damage to cities. Climate change affects port sustainability. Climate change-induced sea level rise and powerful waves may threaten breakwaters and groins.

To fulfil market needs, ports require green-port policies that incorporate social, economic, and environmental aspects.

The numerical model integrates World Ports Sustainability Program (WPSP) infrastructure and digital components. DHI MIKE21 SW numerical modelling is used a digitalized tool to validate the infrastructure of Suez Canal entry groin sustainability against future extreme wave conditions.

The results for the spectral waves height values for different return periods of different directions till 100 years return period conditions show that the values are less than 0.30m for most of Port Said Ports. However, H_s value at the entrance of West Port said Port reaches 0.76m, which needs further sustainable infrastructure planning.

Keywords: Sustainability Development Goals, Sustainable Infrastructure, Suez Canal, Spectral Wave Modelling, DHI MIKE21 SW FM

1. INTRODUCTION

Ports should establish green-port policies interconnected via social, economic, and environmental aspects in accordance with market demands. Several coastal international organizations and projects are increasing awareness of the coastal market needs for meeting the Sustainable Development Goals

(SDGs). Resilience infrastructure of the Cruise touristic ports is one of the main pillars to achieve the sustainability for future-proof Infrastructure for the port-Cities. Tourism growth along the Mediterranean coast has resulted in tremendous urban development, notably along the coastlines of Europe. Because of the environmental implications, the present port infrastructure should be expanded and upgraded in the future.

Nebot (2017) processed prospective port system improvement proposals based on international port literature. These concepts emerged from several fields, but they have now been brought together to provide a holistic understanding of the discussion. These are integrated port management, sustainable resilience infrastructures for ports, port regionalization, connectedness to the landscape and urban regions, and socially integrated ports. In port-city coastal projects, each port has its own city, as is customary in coastal communities. Ports function as economic market integration and service agglomeration while also generating economic advantages. Cities provide the resources and infrastructure necessary for cities to build their ports (Cong et al., 2020).

Port-cities are economically significant institutions that provide a considerable source of maritime activity. They serve as a bridge between both the local and global surroundings. The beneficial spillover effects of the port hinterland tend to be focused on port-cities due to the rapid speed of economic globalization and the continual growth of ports' hinterlands. However, negative consequences of port-city expansion, such as pollution, arise. As a result, sustainable development is a critical factor in increasing port performance (Kong and Liu, 2021).

The World Commission on Environment recommended environmental sustainability in 1987 as a way to establish a community that fulfils our present needs while simultaneously conserving future generations' ability to do so. The United Nations Sustainable Development Summit formally endorsed 17 UN SDGs on September 25, 2015. Sustainable development has emerged as the major objective of coastal planning. The fast expansion of the international market has created an imbalance among socioeconomic development and environmental assets, posing serious social, economic, and environmental threats. Sustainable development was presented as a way of development that satisfies demands without endangering earth capability to satisfy future human needs. Achieving UN SDGs is the most effective way to reduce the harmful impacts of ports on cities (IAPH-WPSP, 2022).

Port adaptation and sustainability depend on climate change. Sea level rise and strong wave characteristics due to climate change might jeopardize breakwaters and groins (Takagi et al., 2011).

DHI MIKE21 SW numerical modelling is used to validate the sustainability of Suez Canal entrance groins during severe wave conditions. The numerical model applies WPSP infrastructure and digitization components to meet market demands, ports need green-port policies that integrate social, economic, and environmental factors (IAPH-WPSP, 2022).

The expansion of different coastal activity and the necessity for world market competition force ports to explore all opportunities for efficiency and reduced cost (Pavlic et al., 2014). Ports can reduce their environmental footprint by applying innovative sustainable infrastructure solutions (Twrdy and Zanne, 2020). For innovated ports, the environment dimension should be prioritized over the social and economic dimensions to attain sustainability (Sengar et al., 2018).

Climate change impact, as main dimension of the environment dimensions for the sustainability, is a critical component to port adaptation and sustainability. Climate change is expected to lead to increases in both sea level and extreme wave characteristics, which could threaten the stability of breakwaters and the groins (Takagi et al., 2011). Ports need to develop green-port policies interlinked via social, economic, and environmental dimensions to strengthen port processes as ports market requirements (Schipper et al., 2017). There are several coastal international organizations and programs which are raising the awareness of the coastal market requirements of achieving UN SDGs, such as World Ports Sustainability Program (WPSP). The International Association of Ports and Harbors (IAPH) developed the WPSP in 2017 to help ports in implementing the 17 UN SDG. The initiative aims to improve and coordinate the future sustainability efforts of ports throughout the globe and to develop international collaboration with the international partners (IAPH-WPSP, 2022).

To study the sustainability of the ports infrastructure and to achieve a future proof infrastructure, ports infrastructure should be validated for the capability to stand against the expected extreme weather events with longer life time, along with the required rehabilitation works if required. Coastal planning prioritizes sustainability as the rapid growth of the global market has caused a socioeconomic development-environmental asset mismatch, creating major social, economic, and environmental dangers. Sustainable development meets requirements without compromising Earth's capacity to meet future needs. SDGs are the best strategy to decrease port damage to cities as climate change affects port sustainability.

Lowe (2005) discovered that projections of future severe sea levels are uncertain, but that changes in atmospheric storminess will result in changes in the height of water levels measured relative to the current storm wave. This could lead to more extreme coastal waves. Additionally, Grabemann (2008) found that towards the end of the twenty first century, global warming may cause extreme wave heights to rise by roughly 0.3 m. This also suggests that climate change will lead to more extreme coastal waves. However, when comparing the years 1961-1990 to the years 2071-2100, Winter (2012) determined that the circumstances of the annual maximum waves in front of the European coast were not expected to alter greatly due to climate change. For high-frequency severe wave occurrences, Morim (2021) revealed that in the Representative Concentration Pathway 8.5 (RCP8.5) high-emission scenario, changes of 50%-100% are predicted, which is roughly twice the estimated changes for RCP4.5 scenario. According to Kaiser (2020) DHI MIKE21 Spectral waves with flexible meshes (DHI MIKE21 SW FM) should be used to get two-dimensional wave heights for Port Said and Suez Canal region based on wave bottom interactions and wave structure interactions.

2. METHODOLOGY

2.1 Introduction

One of the main challenges for port development, such as Port Said Ports, is minimizing long-term uncertainty connected with infrastructure lifespan, such as breakwater lifetime, and substantial environmental consequences. The purpose of this article is to provide a numerical model simulation for evaluating the sustainability performance of the Suez Canal Entrance Groins. In order to analyses and understand future sustainable port-city development plans, this model evaluate a main key performance indicator (KPIs) against future forecasted severe wave conditions.

To study the sustainability of the entrance groins of Suez Canal as a market requirement for Achieving SDGs, DHI MIKE21 SW FM numerical modelling is constructed as shown in Figure 1) to ensure the efficiency of the entrance groins against the extreme wave conditions as a numerical validation analysis.

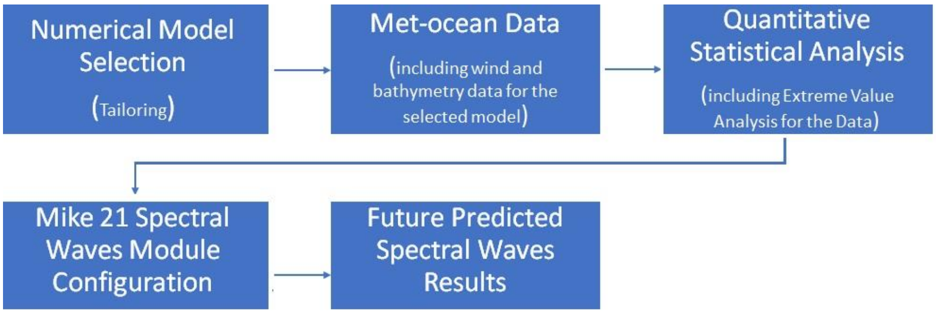

Figure 1: Flow Chart for DHI MIKE21 SW FM Numerical Modelling Generation

2.2 Numerical model selection

For the evaluation of conditions for waves in nearshore or coastal zones that typically requires the transformation of offshore wave statistics. The parametric model that is decoupled in the direction of the wave is recommended for the model. The formulation of directionally decoupled is a formula that can be utilized to generate small-scale wave transportation of waves to ports or shorelines, with a spatial scale can be as large as fifty kilometers. The spectral model is typically employed to predict waves simultaneously as well as analysis on a larger as well as local scales. For the region-scale aspect of the computational domain, it is necessary to have a low spatial and temporal resolution is employed. The full spectrum equation can be applied at various dimensions. This kind of formula is commonly used to forecast waves, and then analyses them using an unstructured mesh. The waters in the shallow areas around the coast should have a high-resolution border as well as depth. Regional modeling employs a small resolution spatial resolution (DHI, 2017).

2.3 Met-ocean data

The quantitative Met-ocean data for the point selected, as shown in Figure 2), was extracted using a multiyear-wave hindcast model that was derived from CMEMS database till the year of 2020, followed by a quantitative Met-Ocean data extracted from the global ocean analysis and prediction system with daily analyses for ocean surface waves and 3-hourly instantaneous fields till the year of 2022 (Copernicus Marine Service, 2022).

Figure 2: Quantitative Met-ocean Data for the Selected Point Location

Sets of preliminary experiments were performed to assess the influence of the reliability of the wave hindcast dataset. These tests for the Worldwide CMEMS dataset allow for a scatter index of less than 10% worldwide. The results show that CMEMS database has variations of H_s values reach -0.12 m on a regional scale of the Mediterranean Sea by using density of comparison data over 1120000 readings from CMEMS's satellite altimeters values and buoy readings (Copernicus Marine Service, 2020). Figure 3 shows comparison between scatter index of H_s for CMEMS and ERA5 results.

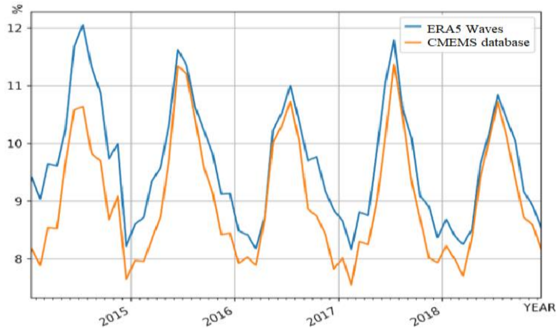

Figure 3: Comparison between shows time series of scatter index of Hs for CMEMS and ERA5 results

2.4 Quantitative statistical analysis

Parametric frequency analysis is utilized to study extreme wave characteristics instances using DHI Mike Zero, with using a threshold value of 0.01m to simulate the predicted significant wave height (H_s) based on the historical dataset of the met-ocean data. Theoretical probability distribution that is fitted into the extreme value series that is observed is used to create the model for extreme values (DHI, 2017). Statistical analysis methods are used to obtain extreme wave characteristics, as shown in Table 1.

Table 1. Statistical Analysis Criteria

Model duration	Partial duration series (PDS)
Probability distribution of the data	Distribution of Weibull
Probability plot correlation for the model	The probability plot correlation coefficient (PPCC)
Uncertainty calculation for the model	Monte Carlo simulation

Figure 4) illustrates the wave rose for different directions, and Figure 5) illustrates the frequency and probability plots for each direction.

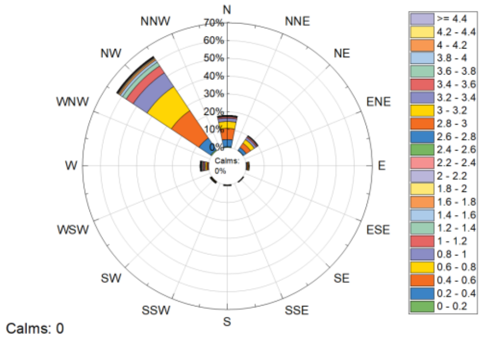

Figure 4: Wave Rose for Different Directions in front of Suez Canal, Port Said

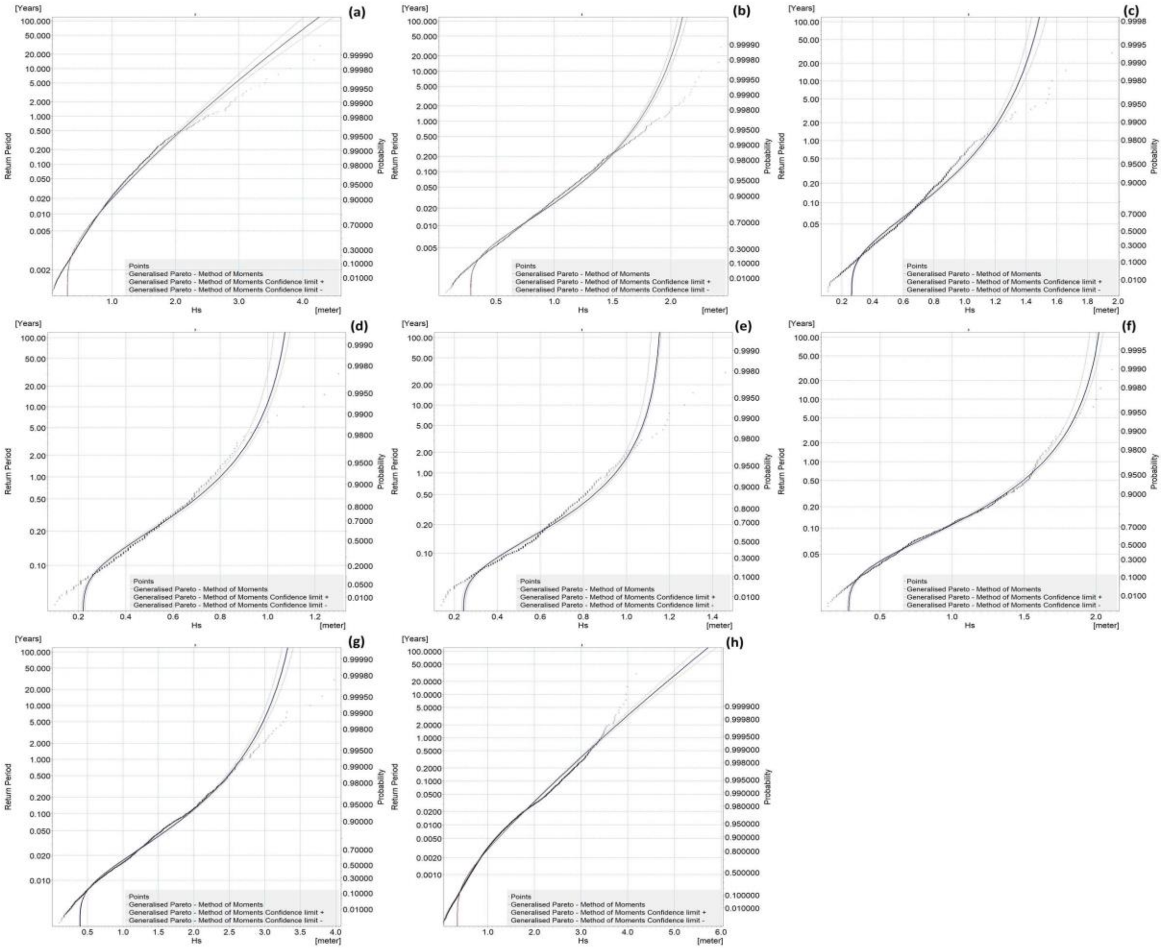

Figure 5: Analyzed Hs Values for Different Direction and Various Return Periods of (a) 0° (b) 45° (c) 90° (d) 135° (e) 180° (f) 225° (g) 270° (h) 315°

2.5 Model bathymetry and mesh

It is essential to give MIKE 21 SW FM with adequate mesh and bathymetry for appropriate results. Mesh is generated to have an appropriate resolution for bathymetry, wind fields, and other relevant factors. The primary purpose of modelling is to specify the depth of water inside the region of the model. The mesh file, including bathymetry, is generated via MIKE Zero Meshing Generator. It is a piece of software that facilitates the construction and manipulation of unstructured meshes. The mesh file is an ASCII file that contains bathymetry and geographic location information for each piece in the mesh (DHI, 2017). Bathymetry data from GEBCO is used to construct the bathymetry. MIKE Zero Mesh Generator is employed to process and build of meshes that are not structured. GEBCO's global terrain model that includes land and oceans and provides elevation data in meters (GEBCO Bathymetric Compilation Group, 2022). Figure 6) illustrates the generated numerical mesh for entrance groins of Suez Canal.

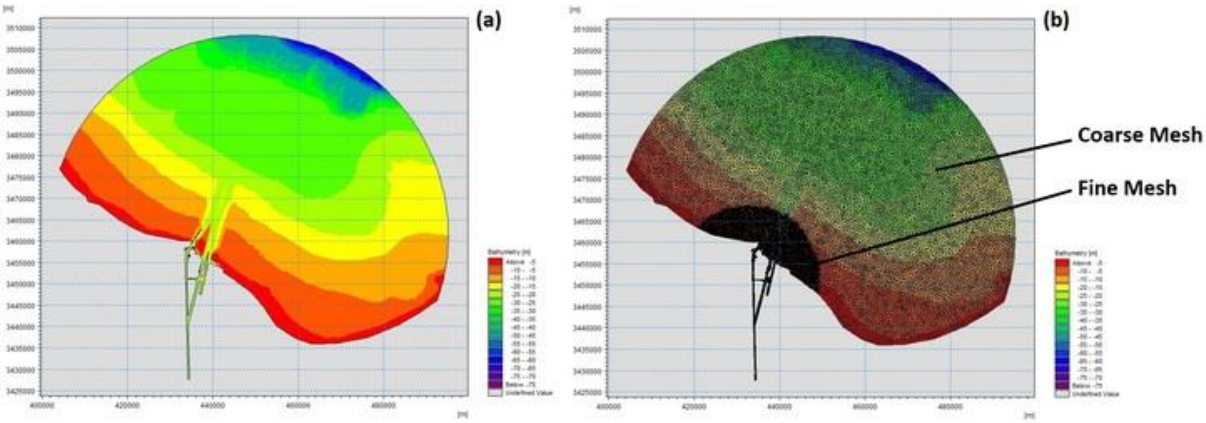

Figure 6: Numerical Mesh for Entrance Groins of Suez Canal (a) Mesh Bathymetry for the Model (b) Fine and Coarse Meshes for the Model

2.6 Model configuration and validation

In order to ensure the model validation, the model configuration is generated in accordance with the guidelines of MIKE21 SW FM by the Danish Hydraulic Institute of spectral wave modeling (DHI, 2017). The model allows wave generation in accordance with extreme wave characteristics of 8 directions for 5 different return periods of 5, 10, 20, 50 and 100 years return periods. Manning number value is considered 32 $m^{1/3}/s$, which is a factor used for future model calibration. MIKE21 SW FM model is built in accordance with the model criteria shown in Table 2.

Table 2. Statistical Analysis Criteria

Model Runs	40 runs of 8 directions in accordance with 5 different return periods of 5, 10, 20, 50 and 100 years Return Period
Model Type	Spectral Wave Flexible Mesh Model with Critical CFL equals 0.95
Wave Breaking	Wave Breaking with specific gamma of 0.8
Bottom Friction	Model of Nikuradse Roughness kn = 0.04
Bed Resistance	Manning Number equals to 32 $m^{1/3}/s$
Initial Conditions	Spectral JONSWAP fetch Growth Generation with Maximum fetch length of 10000 m

3. RESULTS AND RECOMMENDATIONS

Since the entrance groins of Suez Canal are approximately aligned with 30° to North, the related spectral waves height values for different return periods of directions 315°, 0° and 45° are the dominate H_s values for the prediction analysis. Figure 7) illustrates H_s values at the Suez Canal zone for 45° direction for different return period simulations. Figure 8) illustrates H_s values at the Suez Canal Entrance channel line for different direction and various return periods simulations. The results for the spectral waves height values for different return periods of different directions till 100 years return period conditions show that the values are less than 0.30m for Port said Touristic Port, Port said Shipyard, Sherif Basin, West Port said Port and East Port said Port. However, H_s value at the entrance of Port said Military Base reaches 0.76m, as shown in Table 3.

The results shows that the H_s values shall not be safe for maneuvering towards the navigation channel as the results are higher than 3.0 m for Suez Canal prevailing wave direction (PWD) of 315°.

The model is calibrated based on Hs values of the SW FM model results against Mediterranean-SW-WRF model prepared by DHI, from 1979 till 2011 as shown in Figure 9.

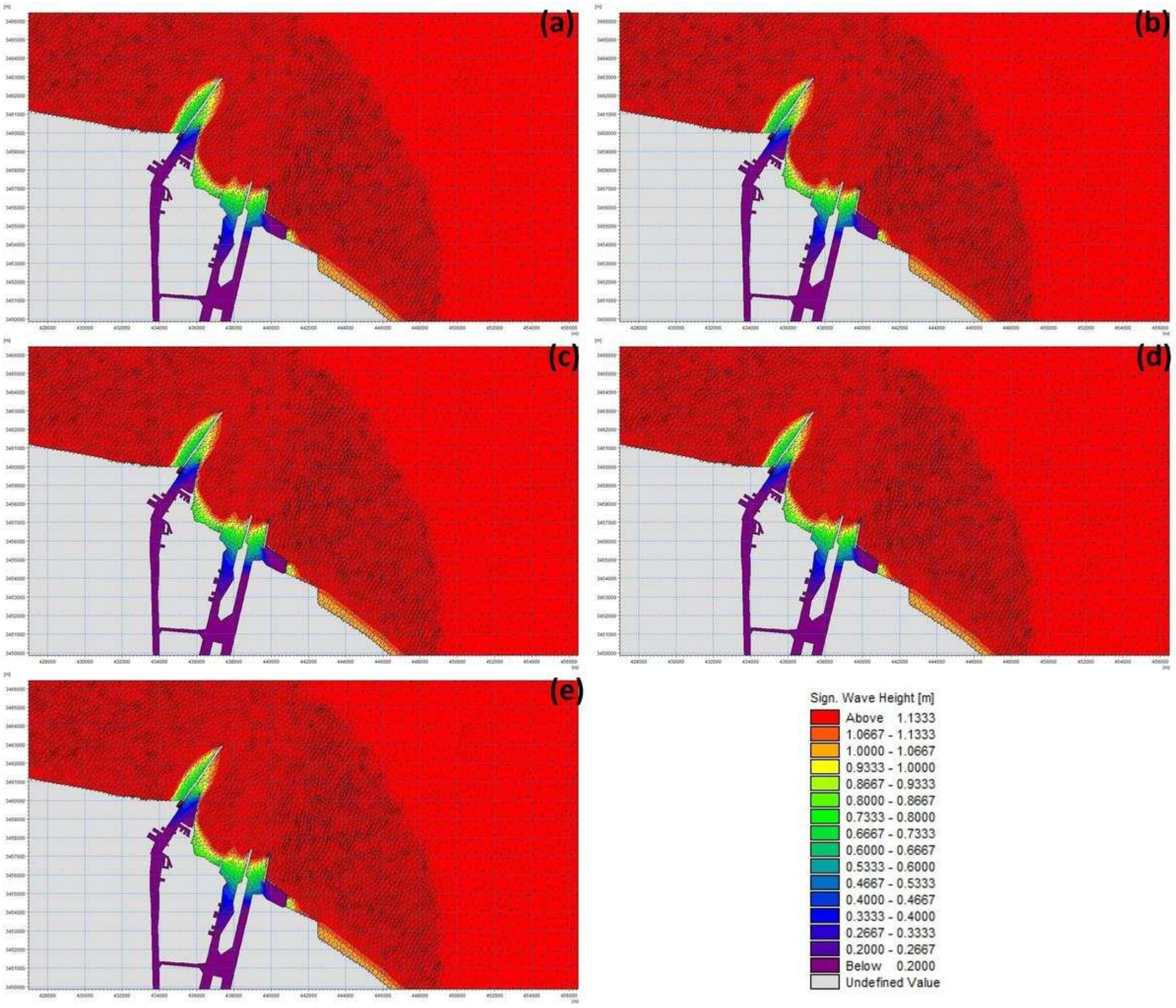

Figure 7: H_s values at the Suez Canal zone for 45° direction for different return period (a) 5 years return period (b) 10 years return period (c) 20 years return period (d) 50 years return period (e) 100 years return period.

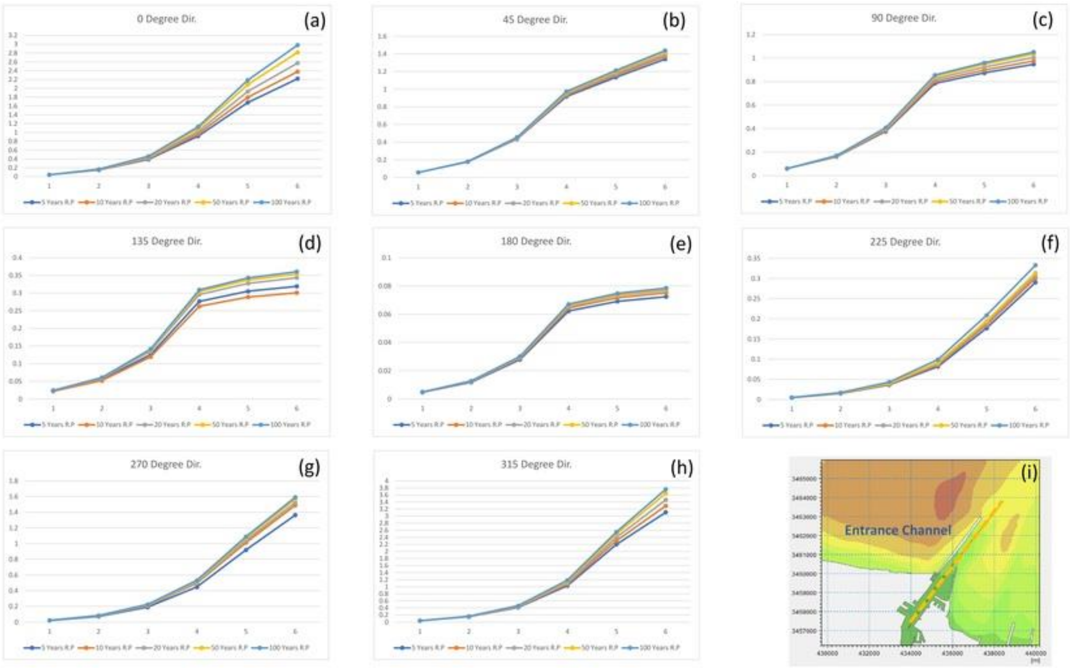

Figure 8: Analyzed H_s Values for Entrance Channel Line for Different Direction and Various Return Periods of (a) 0° (b) 45° (c) 90° (d) 135° (e) 180° (f) 225° (g) 270° (h) 315° (i) Plan View for Entrance Channel Line

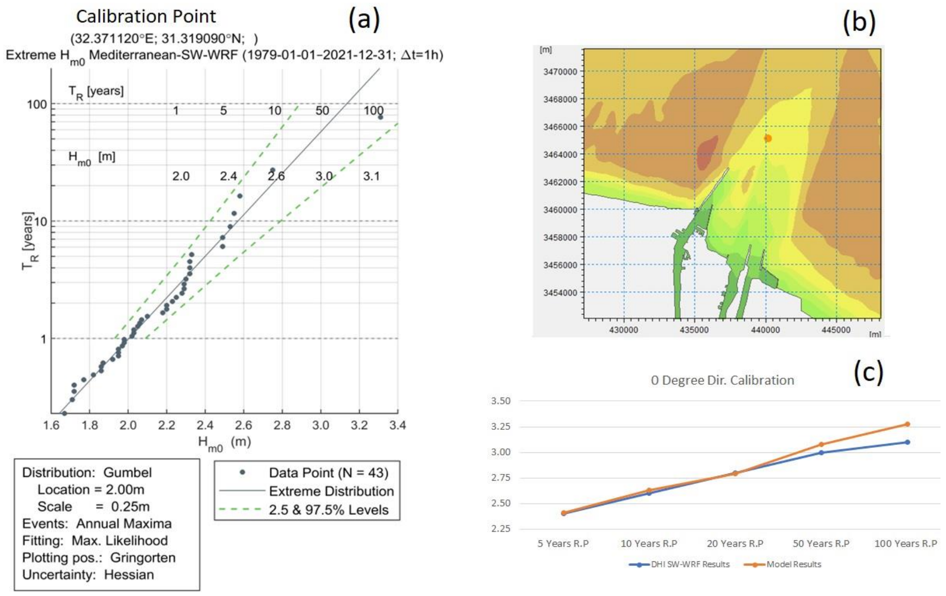

Figure 9: Calibration results (a) Results for SW-WRF Model (b) Calibration Point Location Map (c) Comparison between SW-WRF and Generated Results from the SW FM Model

Table 3. Spectral Waves Results

Return Period (Years)	*Direction (Degree)*	*Port said Touristic Port: H_s (m)*	*Port said Shipyard: H_s (m)*	*Sherif Basin: H_s (m)*	*West Port said Port: H_s (m)*	*East Port said Port: H_s (m)*	*Military Base Entrance: H_s (m)*
5	0	0.23	0.20	0.03	0.03	0.01	0.60
5	45	0.27	0.18	0.04	0.04	0.02	0.72
5	315	0.24	0.22	0.03	0.02	0.01	0.50
10	0	0.24	0.21	0.03	0.03	0.01	0.63
10	45	0.28	0.18	0.04	0.04	0.02	0.73
10	315	0.24	0.23	0.03	0.02	0.01	0.51
20	0	0.25	0.22	0.04	0.03	0.01	0.65
20	45	0.28	0.18	0.04	0.04	0.02	0.74
20	315	0.25	0.24	0.04	0.02	0.01	0.52
50	0	0.26	0.23	0.04	0.03	0.01	0.68
50	45	0.28	0.18	0.04	0.04	0.02	0.75
50	315	0.26	0.25	0.04	0.02	0.01	0.53
100	0	0.27	0.24	0.04	0.03	0.01	0.69
100	45	0.28	0.19	0.04	0.04	0.02	0.76
100	315	0.26	0.26	0.04	0.02	0.01	0.54

Modification for the entrance groin of Port said Military Base and West Port Said Port should be modified to reduce the maximum H_s of 0.60m, to ensure safe future sustainable maneuvering.

5. CONCLUSION

Green-port policies should be social, economic, and environmental to meet market needs. Several coastal international organizations and projects are raising awareness of coastal market SDGs demands. Port-cities are economically important marine hubs. Climate change impacts port adaptation and sustainability. Climate change is anticipated to increased severe wave characteristics, threatening breakwaters and groins. To examine the sustainability of ports infrastructure and build a future-proof infrastructure, ports infrastructure should be verified for its capacity to withstand the predicted severe weather events with extended lifetimes.

Port development, like Port Said Ports, should minimize long-term uncertainties related to infrastructure longevity, such as breakwater lifetime, and significant environmental impacts. This article simulates the sustainability of Suez Canal Entrance Groins using DHI MIKE21 SW FM numerical model. This model analyses a primary key performance indicator (KPI) against future predicted extreme wave conditions to determine sustainable port-city development plans.

Since the Suez Canal entry groins are approximately oriented with 30° to North, the corresponding spectral waves height values for distinct return periods of orientations 315, 0, and 45° dominate the prediction analysis. The spectral H_s values for various return periods of different directions till 100 years return period conditions are less than 0.30m for Touristic Port, Port Said Shipyard, Sherif Basin, West Port, and East Port of Port Said. H_s at the Military Base's port entrance is 0.76m. The entry groins of Port Said Military Base and West Port should be sustainability modified to minimize the maximum H_s of 0.60m for safe and sustainable maneuvering.

It is suggested to study in the future the required sustainable modifications of the entry groins of Port Said Military Base and West Port for safe and sustainable maneuvering. It is also suggested to study the expected storm surges and future sedimentations inside Suez Canal and its ports.

It is suggested study a suitable resilience risk management plan for future threatens in accordance with the main pillars od WPSP to improve and coordinate the future sustainability efforts for Egyptian Ports.

5. REFERENCES

1. Cong, Long-ze, Dong Zhang, Ming-li Wang, Hong-feng Xu, and Li Li. 2020. "The Role of Ports in the Economic Development of Port Cities: Panel Evidence from China." Transport Policy 90 (May): 13–21. https://doi.org/10.1016/j.tranpol.2020.02.003.
2. Copernicus Marine Service. 2020. "Global Ocean Waves Reanalysis WAVERYS." Mercator Ocean International. https://doi.org/10.48670/MOI-00022.
3. Copernicus Marine Service. 2022. "Global Ocean Waves Analysis and Forecast." Mercator Ocean International. https://doi.org/10.48670/MOI-00017.
4. DHI. 2017. "MIKE 21 Spectral Waves FM." User Guide. The Netherlands: DHI. https://www.mikepoweredbydhi.com/products/mike-21/waves/spectral-waves.
5. GEBCO Bathymetric Compilation Group. 2022. "The GEBCO 2022 Grid." Documents,Network Common Data Form. NERC EDS British Oceanographic Data Centre NOC. https://doi.org/10.5285/E0F0BB80-AB44-2739-E053-6C86ABC0289C.
6. Grabemann, Iris, and Ralf Weisse. 2008. "Climate Change Impact on Extreme Wave Conditions in the North Sea: An Ensemble Study." Ocean Dynamics 58 (3–4): 199–212. https://doi.org/10.1007/s10236-008-0141-x.
7. IAPH-WPSP. 2022. "Areas of Interest – World Port Sustainability Program." Periodically Updated. World Port Sustainability Program. 2022. https://sustainableworldports.org/areas-of-interest/.
8. Jugović, Alen, Miljen Sirotić, and Ivan Peronja. 2021. "Sustainable Development of Port Cities from the Perspective of Transition Management." Transactions on Maritime Science 10 (2): 466–76. https://doi.org/10.7225/toms.v10.n02.w01.
9. Kaiser, Mona Fouad, Walaa Awaad Ali, and Maysara Khairy El Tahan. 2020. "Modeling of Coastal Processes in the Mediterranean Sea: A Pilot Study on the Entrance of Suez Canal in Egypt." In Coastal and Marine Environments - Physical Processes and Numerical Modelling, edited by José Simão Antunes Do Carmo. IntechOpen. https://doi.org/10.5772/intechopen.88509.
10. Kong, Yudan, and Jiaguo Liu. 2021. "Sustainable Port Cities with Coupling Coordination and Environmental Efficiency." Ocean & Coastal Management 205 (May): 105534. https://doi.org/10.1016/j.ocecoaman.2021.105534.

11. Lowe, J.A, and J.M Gregory. 2005. "The Effects of Climate Change on Storm Surges around the United Kingdom." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 363 (1831): 1313–28. https://doi.org/10.1098/rsta.2005.1570.
12. Morim, Joao, Sean Vitousek, Mark Hemer, Borja Reguero, Li Erikson, Merce Casas-Prat, Xiaolan L Wang, et al. 2021. "Global-Scale Changes to Extreme Ocean Wave Events Due to Anthropogenic Warming." Environmental Research Letters 16 (7): 074056. https://doi.org/10.1088/1748-9326/ac1013.
13. Mutombo, Kana, and Aykut Ölçer. 2017. "Towards Port Infrastructure Adaptation: A Global Port Climate Risk Analysis." WMU Journal of Maritime Affairs 16 (2): 161–73. https://doi.org/10.1007/s13437-016-0113-9.
14. Nebot, Nuria, Carlos Rosa-Jiménez, Ricard Pié Ninot, and Beatriz Perea-Medina. 2017. "Challenges for the Future of Ports. What Can Be Learnt from the Spanish Mediterranean Ports?" Ocean & Coastal Management 137 (March): 165–74. https://doi.org/10.1016/j.ocecoaman.2016.12.016.
15. Pavlic, Bostjan, Franka Cepak, Boris Sucic, Marko Peckaj, and Bogomil Kandus. 2014. "Sustainable Port Infrastructure, Practical Implementation of the Green Port Concept." Thermal Science 18 (3): 935–48. https://doi.org/10.2298/TSCI1403935P.
16. PIANC. 2014. "Sustainable Ports - a Guide for Port Authorities." EnviCom-WG-150. Belgium: PIANC. the World association for Waterborne transport infrastructure. https://sustainableworldports.org/project/pianc-sustainable-ports-guide/.
17. Project Management Institute, ed. 2021. The Standard for Project Management and a Guide to the Project Management Body of Knowledge (PMBOK Guide). Seventh edition. Newtown Square, Pennsylvania: Project Management Institute, Inc.
18. Schipper, C.A., H. Vreugdenhil, and M.P.C. de Jong. 2017. "A Sustainability Assessment of Ports and Port-City Plans: Comparing Ambitions with Achievements." Transportation Research Part D: Transport and Environment 57 (December): 84–111. https://doi.org/10.1016/j.trd.2017.08.017.
19. Sengar, Vikas Singh, Chandra Prakash Garg, and T. Bangar Raju. 2018. "Assessment of Sustainable Initiatives in Indian Ports Using AHP Framework." International Journal of Business Excellence 16 (1): 110. https://doi.org/10.1504/IJBEX.2018.094580.
20. Shaltout, Mohamed, and Kareem Tonbol. 2011. "Modeling of Wave Propagation off Damietta-Port Said Coast, Egypt." Journal of the Arab Institute of Navigation (AIN) 27 (January): 56–67.
21. Takagi, Hiroshi, Hidehiro Kashihara, Miguel Esteban, and Tomoya Shibayama. 2011. "Assessment of Future Stability of Breakwaters Under Climate Change." Coastal Engineering Journal 53 (1): 21–39. https://doi.org/10.1142/S0578563411002264.
22. Twrdy, Elen, and Marina Zanne. 2020. "Improvement of the Sustainability of Ports Logistics by the Development of Innovative Green Infrastructure Solutions." Transportation Research Procedia 45: 539–46. https://doi.org/10.1016/j.trpro.2020.03.059.
23. United Nations. 2015. "Transforming Our World: The 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs." Sustainable Development Goals. September 2015. https://sdgs.un.org/2030agenda.
24. Winter, Renske C. de, Andreas Sterl, Johannes W. de Vries, Susanne L. Weber, and Gerben Ruessink. 2012. "The Effect of Climate Change on Extreme Waves in Front of the Dutch Coast." Ocean Dynamics 62 (8): 1139–52. https://doi.org/10.1007/s10236-012-0551-7.