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The Effect of Attenuation on Simulation of Tsunami Wave Propagation Using FDM

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***Abstract*— This study seeks to investigate the shape of the surface of tsunami waves using the finite difference method and the effect of the damping function on the simulation of tsunami wave propagation using Matlab-based visualisation. The effect of attenuation on the propagation of tsunami waves is measured by the variation in energy. The results of the investigation indicate that tsunami waves have a transverse wave form, with waves propagating in a perpendicular direction. In the meantime, the analysis of the damping function reveals a decrease in the value of energy; this indicates that if the damping function is provided, it will have the effect of reducing the wave energy and propagation speed of tsunami waves. This modelling clearly and realistically illustrates the results of wave movement visualisation and provides insight for disaster mitigation and coastal protection.**

***Index Terms*— Finite Difference Method, Flores Sea, Matlab, Tsunamis, Wave**

I. INTRODUCTION

INDONESIA is a country susceptible to natural disasters [1], [2]. Indonesia is prone to earthquakes as a result of the release of seismic waves on rocks in the earth's crust [3]. This is due to Indonesia's location above the intersection of the Pacific, Eurasian, and Indo-Australian tectonic plates, which are continuously moving and causing the release of seismic waves on rocks in the earth's crust. One of the most frequent natural catastrophes is an earthquake with a tsunami as a secondary effect of seismic activity. The tsunami catastrophe is one of the most dangerous natural disasters in the coastal region [4]. The Meteorology, Climatology, and Geophysics Agency documented up to 400 earthquakes per month, resulting in 11,660 earthquake events recorded on the Earthquake Repo website in 2019 [5].

East Nusa Tenggara (NTT) is a province in eastern Indonesia, bounded by the Flores Sea to the north, the Indian Ocean to the south, and Timor Leste to the west. The province of NTT is comprised primarily of small islands and groupings. Flores Island is one of the NTT islands that is a part of the Pacific Ring of Fire and exhibits high tectonic activity [6], [7]. This is because of the Flores thrust zone, where the reverse thrust extends from the northern region of Flores to Bali and West Nusa Tenggara. In addition, found that the Flores region is susceptible to tectonic disturbances and produces tsunamis [8], [9].

It is documented that a tsunami struck Flores Island, and the most devastating one occurred 30 years ago, in 1992 [10], [11]. On the eastern and central portions of the island of Flores on December 12, 1992, more than 1,500 people were reported deceased, 500 people were missing, and thousands of structures were damaged. It is estimated that 113 schools and 90 places of worship were destroyed by the earthquake and tsunami, with tsunami surges as high as 6 to 25 metres sweeping the mainland as far as 300 metres after a magnitude 7.5 earthquake shook East Nusa Tenggara Province.

Earthquakes, underwater volcanic eruptions, landslides, and other events that take place on or beneath the seafloor are the main causes of tsunamis [12]–[14]. If the height of the waves does not surpass 1 metre, they are not hazardous. However, it will be hazardous if the concentrated wave energy has a wavelength greater than the depth of the water. When waves enter the shallow water zone, the wave height increases tenfold and the wave speed decreases dramatically. In the past decade, there have been 12 tsunamis caused by 252 earthquakes, resulting in a cumulative loss of 79 trillion rupiah [15]. Therefore, it is necessary to increase knowledge of the physical factors and social engineering associated with disaster mitigation implementation.

Based on disaster mitigation studies, in tsunami-prone areas, it is necessary to have a building to withstand tsunami waves [16]–[18]. In addition, many other nations have conducted a number of studies on reducing disaster risk through the construction of tsunami barriers using analytical research methods and numerical modelling techniques [18].

Researchers are interested in conducting research on tsunami simulations employing attenuation of the wave propagation process based on the aforementioned issues. This attenuation is modelled after the impact of a tsunami surge striking coastal sheet piles. This simulation technique is numerically resolved using the finite difference method [19]–[21]. The finite difference method is beneficial for analysing surface waves and solving partial differential equations [20]. The process of computational numerical simulation will be conducted using an incorporated Matlab web server [22]. Using the finite difference method and simulating the damping value of the sheet pile in the simulation of the impact of the sheet pile on the occurrence of a tsunami, this study aims to ascertain the shape of the tsunami wave surface.

II. METHOD

This research is an integrative effort that combines theoretical and computational methods to produce significant results. Before achieving the aim of this study, a series of theoretical steps must be taken. In the first stage, a comprehensive literature review was carried out using various books, journals and other sources. Through a rigorous literature review, researchers learn how to use Matlab with the Finite Difference Method (FDM) effectively, as well as how to understand and apply mathematical modeling closely to the research problem [23]–[25]. After building a strong theoretical foundation, the next step is to collect relevant data

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to be used as input in the simulation program. Wave parameters, energies and other modeling factors are included in the collected data. To ensure that the simulation results accurately reflect the investigated phenomena, data collection was carried out thoroughly.

After collecting data, the next step is to simulate the system in the Matlab application. The modeling phase of this research is very important because the results will determine the accuracy and dependability of the simulation. Matlab is an instrument used by researchers to simulate computer models derived from theoretical concepts. The Finite Difference Method (FDM) is used because it can provide a numerical solution that accurately represents the system [26]. After the modeling is complete, the researcher runs a simulation using a customized Matlab program. During the simulation process, the results of various scenarios and variables are analyzed and evaluated. This allows the researcher to evaluate the performance of the developed model and identify possible errors or deficiencies in the study.

Before being reported in a scientific report or publication, the results of this investigation go through in-depth analysis. There are also comments regarding the interesting findings, suggestions for further research, and practical applications of this research. It is anticipated that the research findings will make a substantial contribution to our understanding of the phenomenon investigated and have potential applications in a number of related professions or industries. Consequently, these discoveries can have a significant impact on scientific and technological progress. In the context of this investigation, theoretical and computational responsibilities play an important complementary role. The computational techniques allow for additional research through simulation and data analysis, while the theoretical approaches provide a strong conceptual framework. The combination of the two methodologies provides researchers with the opportunity to investigate deeper understandings of complex phenomena, while increasing the applicability of research findings.

In addition to its theoretical merits, this research has considerable application potential. The results and models produced can be applied in a variety of real-world contexts, such as industrial engineering, related disciplines, and even technology development closely related to the system under investigation. Consequently, this research has relevance beyond the domain of academia and has the potential to provide workable solutions to complex contemporary problems. The complete research flow is presented in Figure 1

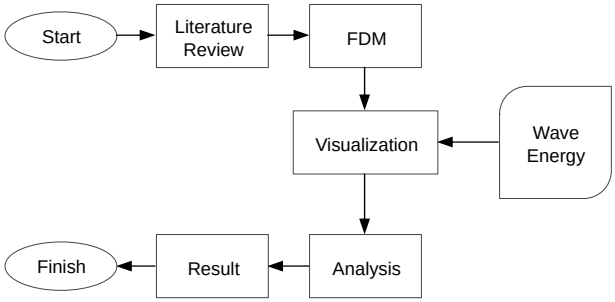


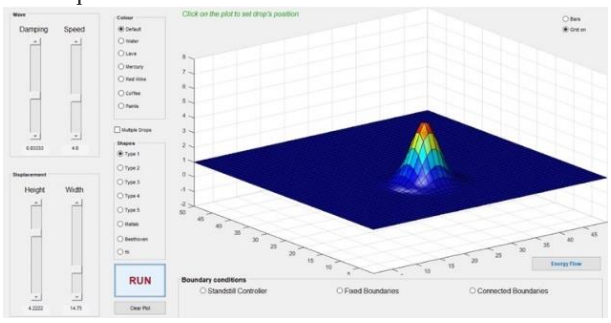
Fig. 1. Research flow

III. Result and Discussion

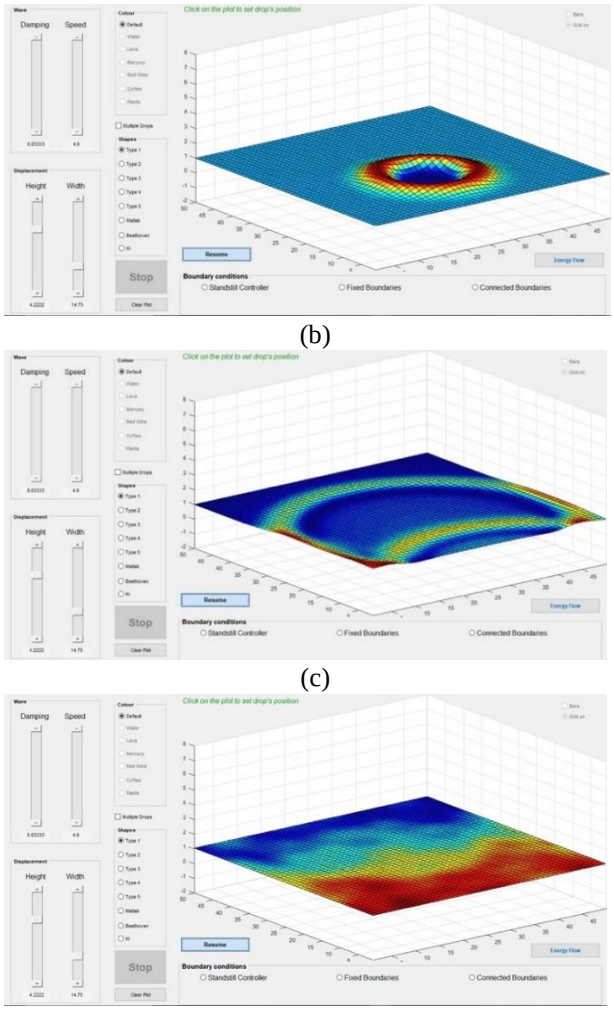
Numerical modelling research has emerged as a popular strategy for understanding tsunami wave behaviour and identifying effective disaster prevention measures [27]. This research aims to simulate the attenuating effects of a tsunami. To calculate the damping effect on wave energy and velocity and to mathematically elucidate wave motion, numerical modelling is utilized [28], [29]. Simulation-generated data was analysed using Matlab, a tool that enables researchers to examine simulation results in greater detail. The contour of the sea surface has a significant effect on the height and velocity of the ensuing waves, according to the tsunami wave simulation. This simulation uses the x, y, and z dimensions of three-dimensional modelling to more precisely depict the movement of the tsunami waves (Figure 2). The simulation process is triggered by a disturbance on the sea surface, such as a droplet striking the water, which causes the disturbance to propagate hyperbolically. The Neumann boundary condition is used to initialise this event as a boundary condition once it reaches the periphery. The generated tsunami waves will continue to recur and undergo reflections due to the remaining wave amplitude.

The significance of the damping effect is related to the energy that generates the tsunami in this simulation [30]–[32], which is primarily the consequence of the up fault shown in Figure 3. The simulation's application of attenuation influences the top wave's amplitude, the bottom wave's propagation velocity, and the top wave's amplitude height. As the pressure between the waves and the beach's bottom increases, the pace of wave propagation below slows down. However, the upper wave will have a greater amplitude. Because of the three-dimensional modelling, this simulation provides a more in-depth comprehension of the behaviour of tsunami waves.

Figures 2 and 3 depict the results of the tsunami wave simulation. These images illustrate how wave energy and velocity fluctuate with varying attenuation. By providing a greater understanding of the attenuation effect of tsunami waves, it is believed that these findings will aid in the development of more effective disaster mitigation techniques.



(a)



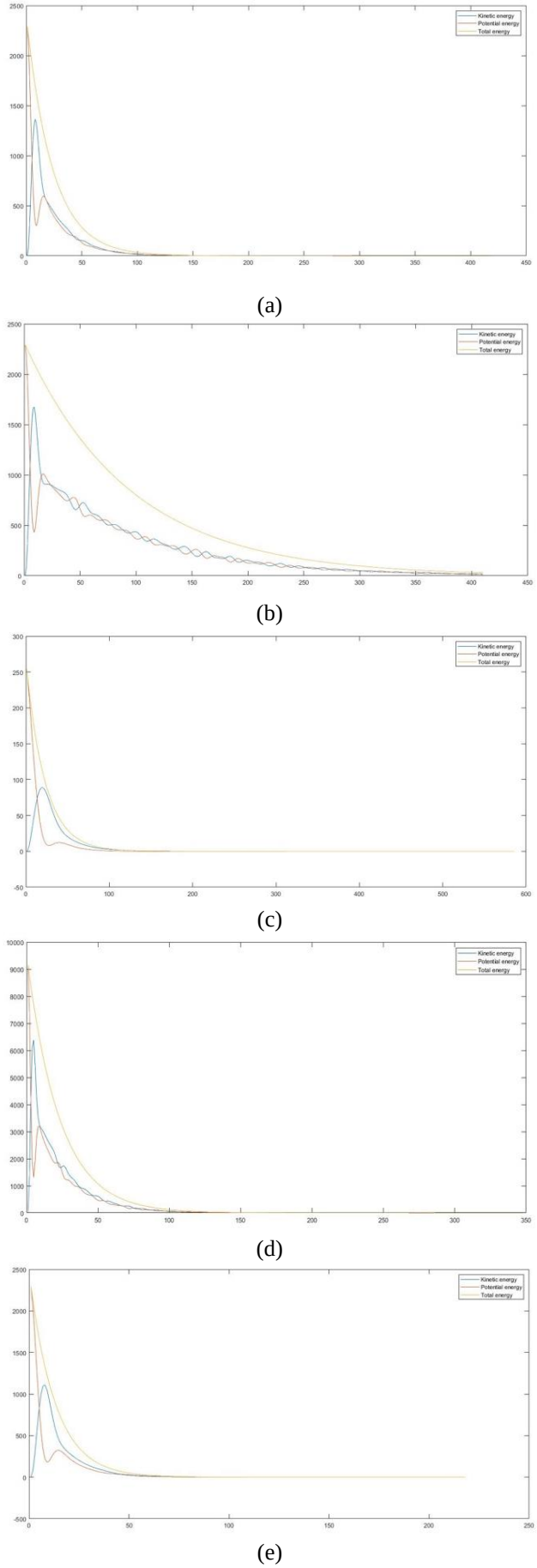
(b)

(c)

(d)

Fig. 2. The process of attenuation of tsunami waves. Where Figure (a) initial appearance, (b) altitude, (c) speed and, (d) width with a speed of 4.6 m/s

Figure 2 is results provide a foundation for comprehending the significance of the energy shift resulting from each damping application, which is illustrated in greater detail in Figure 3. Figure 3.a depicts the results of applying 0.8 damping to a 4.6 m/s wave; Figure 3.b depicts the results of applying 0.2 attenuation to a 4.6 m/s wave, and Figure 3.c depicts the results of applying 0.8 attenuation to a 1.5 m/s wave. Figure 3.d depicts two conditions: an attenuation of 0.8 with a wave speed of 9.2 m/s and an attenuation of 1.5 with a wave speed of 4.6 m/s. Each figure depicts a unique pattern of energy loss, which is influenced by various combinations of attenuation values and wave velocities. According to the research depicted in Figure 3, the attenuation provided by the damping variable and wave speed can result in a decrease in the velocity and energy of the tsunami waves [26], [27], [33], [34]. Therefore, sheet pile attenuation is an effective method for mitigating the destructive effects of tsunami waves. These findings increase our understanding of the potential for catastrophe mitigation via attenuation, particularly in regards to tsunami waves.



(a)

(b)

(c)

(d)

(e)

Fig. 3. Based on the damping speed values given with (a) Damping 0.8 speed 4.6 m/s, (b) Damping 0.2 speed 4.6 m/s, (c) Damping 0.8 speed 1.5 m/s, (d) Damping 0.8 speed 9.2 m/s, (e) Damping 1.5 speed 4.6 m/s.

This model more accurately depicts wave motion by taking into consideration how waves interact with complex sea surface structures. Findings from the simulation are essential for comprehending how tsunami waves affect coastal communities and for assisting in the development of more effective disaster mitigation plans.

This simulation does, however, contain constraints and assumptions that must be considered. Several variables, such as bedrock properties, beach morphology, and atmospheric dynamics, can influence the simulation results; these must be carefully considered. Human factors such as population density, infrastructure, and early warning systems must also be considered in the analysis of the risk of a tsunami wave disaster. Overall, these simulations of tsunami waves provide valuable insight into the complexity of the phenomenon and how the waves interact with the ocean floor [4]. If we have a greater understanding of the behaviour of tsunami waves, we can take more effective precautions and mitigation measures to protect people and the environment against this potential hazard. In addition, it is anticipated that additional research and development in this area will enhance the precision and accuracy of tsunami wave predictions in the future.

IV. Conclusion

The initial conditions of the wave equation are used in the Matlab simulation of tsunami waves to calculate the movement and evolution of waves over time. This simulation method accurately represents the two-dimensional, single-source wave behaviour, especially the motion of the sea surface. Based on the simulation results, the tsunami wave has a transverse wave shape, meaning it propagates in the opposite direction from its propagation. In addition, by analysing the attenuation function, this simulation shows a decrease in the value of the wave energy. The simulation of using a retaining wall as a damper function affects the speed of the tsunami wave propagation. These results indicate that the energy and velocity of tsunami waves will decrease if retaining walls are used as a mitigation material for coastal areas. Thanks to these simulations, the behaviour of the tsunami waves and the damping function can be better understood. Matlab modelling for this simulation can provide a clear and realistic visualisation of wave motion, providing valuable insights for disaster mitigation and coastal protection. However, this simulation contains limitations and assumptions that must be considered. A number of variables can affect the simulation results, which must be considered with care. These variables include the topography of the seabed, the accuracy of data input, and the complexity of phenomena. In order to improve the accuracy and validity of the simulations and to deal with the threat of tsunami waves in a more realistic way, additional research and more complex modelling are required.

References and Footnotes

[1] R. E. Caraka *et al.*, "Cluster Around Latent Variable for Vulnerability Towards Natural Hazards, Non-Natural Hazards, Social Hazards in West Papua," *IEEE Access*, vol. 9, pp. 1972–1986, 2021, doi: 10.1109/ACCESS.2020.3038883.

[2] L. P. R. Kumala Dewi and T. Dartanto, "Natural disasters and girls vulnerability: is child marriage a coping strategy of economic shocks in Indonesia?," *Vulnerable Child Youth Stud*, vol. 14, no. 1, pp. 24–35, Jan. 2019, doi: 10.1080/17450128.2018.1546025.

[3] A. Jufriansah, Y. Pramudya, A. Khusnani, and S. Saputra, "Analysis of Earthquake Activity in Indonesia by Clustering Method," *Journal of Physics: Theories and Applications*, vol. 5, no. 2, p. 92, Sep. 2021, doi: 10.20961/jphystheor-appl.v5i2.59133.

[4] A. Khusnani, A. Jufriansah, and M. Afriyanto, "Utilization of Seismic Data as a Tsunami Vulnerability Review," *Indonesian Review of Physics*, vol. 5, no. 2, pp. 66–72, 2022.

[5] I. R. Pranantyo and P. R. Cummins, "Multi-Data-Type Source Estimation for the 1992 Flores Earthquake and Tsunami," *Pure Appl Geophys*, vol. 176, no. 7, pp. 2969–2983, 2019, doi: 10.1007/s00024-018-2078-4.

[6] L. Handayani, "Seismic Hazard Analysis of Maumere, Flores: a Review of the Earthquake Sources," in *Proceedings of the Proceedings of the 7th Mathematics, Science, and Computer Science Education International Seminar, MSCEIS 2019, 12 October 2019, Bandung, West Java, Indonesia*, EAI, 2020. doi: 10.4108/eai.12-10-2019.2296247.

[7] S. Goes, L. Ruff, and N. Winslow, "The Complex Rupture Process of the 1996 Deep Flores, Indonesia Earthquake (Mw 7.9) from Teleseismic P-waves," *Geophys Res Lett*, vol. 24, no. 11, pp. 1295–1298, 1997, doi: 10.1029/97GL01245.

[8] R. Maneno, B. J. Sentosa, and G. Rachman, "Relocation Of Earthquake Hypocenter In The Flores Region Using Hypo71," *IPTEK The Journal of Engineering*, vol. 5, no. 2, May 2019, doi: 10.12962/j23378557.v5i2.a5024.

[9] I. R. Pranantyo, M. Heidarzadeh, and P. R. Cummins, "Complex tsunami hazards in eastern Indonesia from seismic and non-seismic sources: Deterministic modelling based on historical and modern data," *Geosci Lett*, vol. 8, no. 1, p. 20, Dec. 2021, doi: 10.1186/s40562-021-00190-y.

[10] J. Beckers and T. Lay, "Very broadband seismic analysis of the 1992 Flores, Indonesia, earthquake (Mw = 7.9)," *J Geophys Res Solid Earth*, vol. 100, no. B9, pp. 18179–18193, Sep. 1995, doi: 10.1029/95JB01689.

[11] A. Jufriansah *et al.*, "Estimation of Flores Sea Aftershock Rupture Data Based on AI," *Indones. Rev. Phys*, vol. 6, no. 1, pp. 46–56, 2023, doi: 10.12928/irip.v6i1.6705.

[12] Y. Nishikawa *et al.*, "Observation and simulation of atmospheric gravity waves exciting subsequent tsunami along the coastline of Japan after Tonga explosion event," *Sci Rep*, vol. 12, no. 1, p. 22354, Dec. 2022, doi: 10.1038/s41598-022-25854-3.

[13] Y. Chang, N. C. Mitchell, and R. Quartau, "Landslides in the Upper Submarine Slopes of Volcanic Islands: The Central Azores," *Geochemistry, Geophysics, Geosystems*, vol. 22, no. 10, Oct. 2021, doi: 10.1029/2021GC009833.

[14] C. Zhu, J. Peng, and Y. Jia, "Marine geohazards: Past, present, and future," *Eng Geol*, vol. 323, p. 107230, Sep. 2023, doi: 10.1016/j.enggeo.2023.107230.

[15] A. Z. Arifin, "Simulasi Dampak Penghalang pada Gelombang Tsunami Menggunakan Persamaan Air Dangkal dengan Metode Beda Hingga," *Jambura Journal of Mathematics*, vol. 3, no. 2, pp. 93–102, May 2021, doi: 10.34312/jjom.v3i2.10068.

[16] Syamsidik, T. M. Rasyif, H. M. Fritz, Y. Idris, and I. Rusydy, "Fragility based characterization of alternative tsunami evacuation buildings in Banda Aceh, Indonesia," *International Journal of Disaster Risk Reduction*, vol. 88, p. 103607, Apr. 2023, doi: 10.1016/j.ijdrr.2023.103607.

[17] C. Reis, M. Lopes, M. A. Baptista, and S. Clain, "Towards an integrated framework for the risk assessment of coastal structures exposed to earthquake and tsunami hazards," *Resilient Cities and Structures*, vol. 1, no. 2, pp. 57–75, Jun. 2022, doi: 10.1016/j.rcns.2022.07.001.

[18] U. Gunarathna, C. S. Bandara, R. Dissanayake, and H. Munasinghe, "Tsunami-resilient building guidelines for Sri Lankan coastal belt: a critical review and consolidation based on significant institutional perceptions," *Int J Disaster Resil Built Environ*, May 2023, doi: 10.1108/IJDRBE-06-2022-0058.

[19] A. Mizutani and K. Yomogida, "Source estimation of the tsunami later phases associated with the 2022 Hunga Tonga volcanic eruption," *Geophys J Int*, vol. 234, no. 3, pp. 1885–1902, Apr. 2023, doi: 10.1093/gji/ggad174.

[20] K. Sato, K. Kawasaki, and S. Koshimura, "A numerical study of the MRT-LBM for the shallow water equation in high Reynolds number flows: An application to real-world tsunami

simulation," *Nuclear Engineering and Design*, vol. 404, p. 112159, Apr. 2023, doi: 10.1016/j.nucengdes.2023.112159.
[21] P. Heinrich, A. Jamelot, A. Cauquis, and A. Gailler, "Taitoko, an advanced code for tsunami propagation, developed at the French Tsunami Warning Centers," *European Journal of Mechanics - B/Fluids*, vol. 88, pp. 72–88, Jul. 2021, doi: 10.1016/j.euromechflu.2021.03.001.
[22] G. Ivan, S. Nikolay, L. Vladislav, and P. Andrei, "Solving of Mathematical Problems in the C# Based on Integration with MATLAB," in *2020 Ural Symposium on Biomedical Engineering, Radioelectronics and Information Technology (USBEREIT)*, IEEE, May 2020, pp. 432–435. doi: 10.1109/USBEREIT48449.2020.9117751.
[23] M. Cakmakci, G. Kiziltas Sendur, and U. Durak, "Simulation-Based Engineering," 2017, pp. 39–73. doi: 10.1007/978-3-319-61264-5_3.
[24] P. Zhang, L. Bai, Z. Wu, and L. Guo, "Applying the Parabolic Equation to Tropospheric Groundwave Propagation: A review of recent achievements and significant milestones," *IEEE Antennas Propag Mag*, vol. 58, no. 3, pp. 31–44, Jun. 2016, doi: 10.1109/MAP.2016.2541620.
[25] S. A. Lima, Md. Kamrujjaman, and Md. S. Islam, "Numerical solution of convection–diffusion–reaction equations by a finite element method with error correlation," *AIP Adv*, vol. 11, no. 8, Aug. 2021, doi: 10.1063/5.0050792.
[26] A. Jufriansah, Y. Pramudya, A. Hermanto, and A. Khusnani, "Surface Wave Topography using The 4 Point FDM Simulator," *Science and Technology Indonesia*, vol. 5, no. 4, p. 117, Oct. 2020, doi: 10.26554/sti.2020.5.4.117-120.
[27] A. Jufriansah, A. Hermanto, M. Toifur, and E. Prasetyo, "Investigation of the physics phenomena of weakly damped wave equations with forced force: theory and simulation," *J Phys Conf Ser*, vol. 1567, no. 2, p. 022012, Jun. 2020, doi: 10.1088/1742-6596/1567/2/022012.
[28] A. Elhanafi, A. Fleming, G. Macfarlane, and Z. Leong, "Numerical energy balance analysis for an onshore oscillating water column–wave energy converter," *Energy*, vol. 116, pp. 539–557, Dec. 2016, doi: 10.1016/j.energy.2016.09.118.
[29] D. Lecoanet *et al.*, "Numerical simulations of internal wave generation by convection in water," *Phys Rev E*, vol. 91, no. 6, p. 063016, Jun. 2015, doi: 10.1103/PhysRevE.91.063016.
[30] F. Imamura and C. Goto, "Truncation Error in Numerical Tsunami Simulation by the Finite Difference Method," *Coastal Engineering in Japan*, vol. 31, no. 2, pp. 245–263, Dec. 1988, doi: 10.1080/05785634.1988.11924496.
[31] H. Zhang, M. Zhang, Y. Ji, Y. Wang, and T. Xu, "Numerical study of tsunami wave run-up and land inundation on coastal vegetated beaches," *Comput Geosci*, vol. 132, pp. 9–22, Nov. 2019, doi: 10.1016/j.cageo.2019.06.010.
[32] S. M. Abadie, J. C. Harris, S. T. Grilli, and R. Fabre, "Numerical modeling of tsunami waves generated by the flank collapse of the Cumbre Vieja Volcano (La Palma, Canary Islands): Tsunami source and near field effects," *J Geophys Res Oceans*, vol. 117, no. C5, p. n/a-n/a, May 2012, doi: 10.1029/2011JC007646.
[33] M. Ziaadini-Dashtekhaki, M. Ghaeini-Hessaroeyeh, and S. Hamzehei-Javaran, "Numerical Simulation of Run-Up and Land Inundation on the Vegetated Sloping Beach," *Journal of Earthquake and Tsunami*, vol. 15, no. 06, Dec. 2021, doi: 10.1142/S1793431121500275.
[34] A. Jufriansah, A. Khusnani, A. Hermanto, M. Toifur, and E. Prasetyo, "The Existence of Fourier Coefficients and Periodic Multiplicity Based on Initial Values and One-Dimensional Wave Limits Requirements," *Jurnal Penelitian Fisika dan Aplikasinya (JPFA)*, vol. 10, no. 2, p. 146, 2020, doi: 10.26740/jpfa.v10n2.p146-157.



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