



A New Multi-Purposes Flume Experiments Facility: Challenges and Opportunity for Tsunami and Coastal Engineering in Indonesia

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Abstract

Physical modelling for tsunami engineering is rather difficult to conduct due to lack of comprehensive and advanced facilities to do so. Large number of simulations of the tsunami impacts were performed numerically. In early 2023, a new advanced tsunami flume facility has been completed at Tsunami and Disaster Mitigation Research Center (TDMRC) of Universitas Syiah Kuala. This flume has 60 m in length, 2.5 m in width, and 1.7 m in height. The flume is also equipped with a number of wave, pressure, and current sensors, Particle Image Velocimetry (PIV) Camera, and a laser bed profiler. Beside of the tsunami generator, this flume is also capable to generate wind-driven waves (with two large wind turbines), regular and irregular waves, and currents. The flume provides new opportunities as well as challenges for tsunami scientists and engineers in Indonesia to collaborate and to perform novel researches in tsunami mitigation. This article is aimed at elucidating technical challenges and opportunities in performing tsunami physical models with the large tsunami flume. we performed a series numerical models using DualSPHysic. The results show that composite beach slopes inside the flume has succesfully mimic shallow coast effects that later deformed the incoming tsunami waves into breaking, bores, and runup. Challenges were identified in absorbing tsunami waves with more than one incoming wave to the observation area. In the future, this facility will be accessible for scientists and engineers to collaborate in tsunami science and engineering researches.

Keywords: Tsunami; flume; experiments; DualSPHysic; pressure tank; runup.

Introduction

Assessing flow fields and impacts of waves on structures could be performed in several ways, namely laboratory experiments, field surveys, and numerical simulations. Tsunami waves are long- and rapidly change-waves where their flow regimes are difficult to observe (Schimmels, Sriram, & Didenkulova, 2016). For assessing the tsunami flow fields and impacts of tsunami waves on structures, we need to combine all the three mentioned measures in order to obtain valid and reliable results. In doing so, we will need a long tsunami flume that can facilitate the experiments. Furthermore, coupling waves with wind is of recent interests in coastal hazard studies, especially in



dealing with storm surges experiments (Giridhar & Reddy, 2015; Spencer et al., 2016). However, it is well understood that such facilities are rare and difficult to access in most of cases.

The urgency of having such facilities in Indonesia is certain as this country faces constant threats from multiple types of coastal hazards, including tsunami, erosion, and coastal flooding (Meilianda, Mauluddin, Pradhan, & Sugianto, 2023; Ziana, Azmeri, Yulianur, & Meilianda, 2022). In recent years, the needs become more urgent as mechanism of some new tsunamis have driven many questions to the process that triggered the events and ways to mitigate them (Kirby et al., 2022; Løvholt, Glimsdal, & Harbitz, 2020). However, the facilities are not widely available in Indonesia. In Indonesia, there are three only facilities that can simulate the tsunami in large scale of models. The first one is a tsunami flume managed by Ministry of Research and Innovation of Indonesia (BRIN) in Yogyakarta. The second one is a set of flume and basin managed by a Coastal Engineering Research Center (Balai Teknik Pantai) of Ministry of Public Works of Indonesia in Bali. The latest one is a multi-purposes flume operated by Tsunami and Disaster Mitigation Research Center (TDMRC) of Universitas Syiah Kuala in Banda Aceh. Until the present, there are not more than 5 SCOPUS Indexed research publications that were done using tsunami facilities in Indonesia (Kuswandi, 2023; Triatmadja, Rahardjo, & Yuwono, 2019; Triatmadja, Yuwono, & Nurhasanah, 2020). This also resembles the limitation of research facilities in Indonesia that can facilitate the coastal engineering research. Although in recent years the number of disaster related researches in Indonesia has increased sharply (Djalante, 2018; Djalante & Garschagen, 2017), this does not reflects in the number of coastal engineering researches using physical models methods.

This article is aimed at elaborating technical advantages of the newly developed tsunami wave flume facilities at TDMRC of USK and at highlighting challenges for the facilities to respond the needs of coastal hazards mitigation in Indonesia. As this is the first ever multi-purposes flume experiment facility in Indonesia that combines four driven hydrodynamic forces (tsunami, waves, currents, and winds), therefore, this will be the first article that publishes the establishment of the flume as an advanced coastal engineering laboratory in Indonesia.

Methods

Engineering Set-Up

The flume has four main functions of facilities, namely tsunami wave, regular/irregular waves, currents, and winds. The functions are supported with an underground tank that stores around 230 m³ of water for experiments. In this section, we describe detailed components of each facilities and engineering set-up of the components. A complete sketch of the facilities can be seen in Figure 1. The flume facilities are placed inside a workshop and fully covered by concrete walls and a roof structure. The foundations of the flume structure are supported by a number of piles foundation structures to prevent any settlement and any deformation of the flume structure. Furthermore, to prevent any leaks, all wall structures of the flume are made from waterproof reinforced concrete materials. Table 1 shows a comparison of TDMRC USK Tsunami-Wave Flume facilities with other similar facilities in the world. In term of size/dimensions, TDMRC USK Tsunami Wave Flume is smaller than the other four facilities. However, the facilities could fairly deliver similar objectives to the other larger facilities.

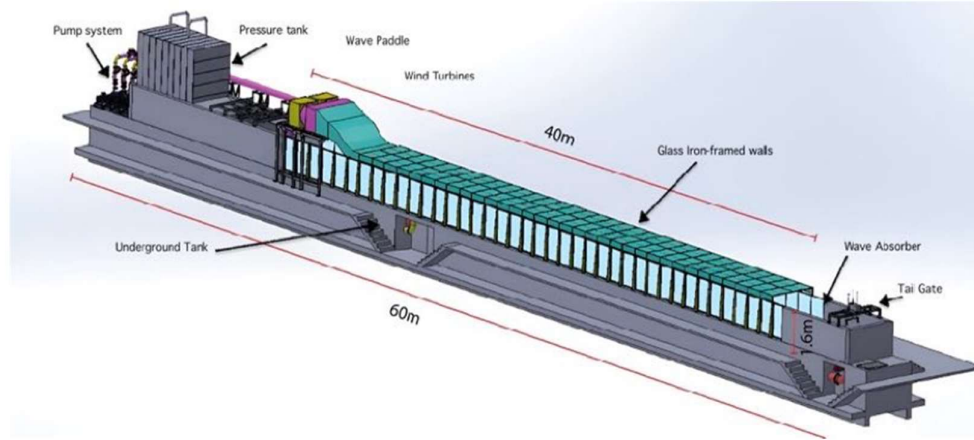


Figure 1. The complete set-up of the multi-purpose flume at TDMRC USK.

Tsunami Generator

The tsunami waves in this flume adopts the generation mechanism introduced by Chandler et al (Chandler, Allsop, Robinson, & Rossetto, 2021). The tsunami waves simulator was produced by HR Wallingford of the United Kingdom. This flume has dimensions 60 m in length, 2.5 m in width, and 1.7 m in height. The maximum water level it can accommodate is up to 1.2 m from the bottom of the flume. To generate the tsunami, one pressure tank is placed at one end of the flume (see Figure 2 a). This pressure tank is controlled by a computer system. The system controls the negative pressure in the tank generated by two sets of vacuum pumps. As the vacuum pumps are working, the water in the flume recedes from its initial level until targeted water level in the flume or in the pressure tank. The control of the vacuum pumps is based on a control valve at the top of the tank. To smoothly generate the tsunami flow without creating any bubbles/bores, a flow shaper is installed the lower part of the pressure tank.

Table 1. A comparison between TDMRC USK Tsunami-Wave Flume Facilities and Other Similar Facilities in the world.

Name of Facility	Location (city, country)	Size (Length, Width and Height) in m	Wave Generation	References
HR Wallingford	Wallingford, UK	100 m, 1.8 m, 1.0 m	Tsunami, regular wave, irregular wave, wave spectra	McGovern et al., 2016
Large Hydro-Geo Flume, Port and Airport Research Institute	Yokohama, Japan	184 m, 3.5 m, 12 m	Tsunami, regular and irregular waves	Shimosako et al., 2002.
Large Wave Flume, Hinsdale Wave Research Laboratory	Oregon State University, US	104 m, 3.7 m, 4.6 m	Tsunami, Tsunami, regular and irregular waves	Lomonaco et al., 2020.

Delta Flume, Deltares	Delft, Netherland	291 m, 5 m, 9.5 m	Regular and irregular waves	Hofland et al., 2014.
TDMRC USK Tsunami-Wave Flume	Banda Aceh, Indonesia	60m,2.5 m, 1.7 m	Tsunami, regular wave, irregular wave, wave spectra	Arifullah et al., 2023

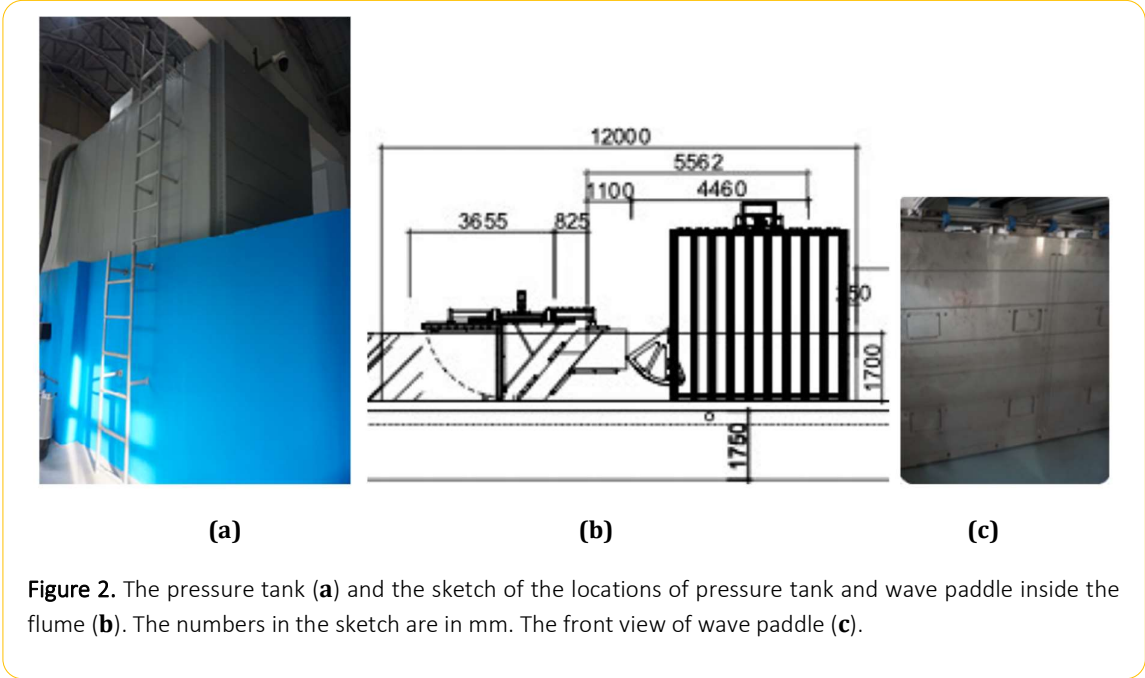
This tsunami system can be used to generate a tsunami with a physical model scale between 1:50 and 1:200. With such scales, runup process at the beach profile model can be observed better. The range of the scales could also facilitate some macro-observations for offshore tsunami propagations.

Wave Generator

The wave generator is made from one wave paddle equipped with a series of pistons to push and pull the paddle in order to generate waves. In the flume, the wave generator is set about 1.1 m from the tsunami flow shaper (see Figure 2 c at the right panel). The wave paddle is also equipped with active wave absorption sensors as in the long experiments, the propagating waves will be reflected from another end of the flume. The active wave absorption sensors could also minimize the bias of the results of the targeting propagated waves. The whole system and material of the wave generator were constructed by HR Wallingford of the United Kingdom.

The wave generator can generate wave types as follows:

- Wave Spectra (JONSWAP, Pierson-Moskowitz, International Towing tank Congress Darbyshire Coastal, Darbyshire Ocean, Neuman, BTTP, Top-Hat, and Bretschneider);
- Regular waves, with variation of wave amplitude and frequency;
- Solitary waves; and
- Time Series.



Current Generator

The flume can also simulate current-based experiments as in the case of a river flow. To generate the current, the water from underground tank is pumped and circulated inside the flume using four sets of Ebara pumps (see **Figure 3**). The pump system is controlled by a computer system to make the current flow become transient and easy to adjust. The pump system is expected to discharge the water inside the flume up to 850 l/s. With combination of the discharge and flow depth of the flume, the maximum current velocity can be set up to 0.3 m/s. To direct the current direction as well as to make the flow more stable, a flow straightener is put inside the flume when discharging the current. **Figure 3** shows the pump system and the flow straightener. According to the early test after the installment, this system requires about 5 m from the outlet of the straightener until the current more stable and ready to be measured for impacts/flow regimes.



Figure 3. The pump system (a) and the flow straightener (b).

Wind Generator

Experiments combining between waves (regular/irregular/spectral waves) and winds are rare. This is because the technical difficulties to install both generators on the same flume. In these new multi-purposes' facilities, we deploy two coaxial fans to generate up to 25 m³/s. The system is made adjustable with Human Machine Interface (HMI) control panel and a sensor for air flow. One airflow straightener is set to direct the air flow inside the flume and make it more stable. Acrylic and Fiber reinforced plastic-made hoods (FRP) are installed on the top of the flume to enable the flow to be contained inside the flume. **Figure 4** shows the wind generator of the flume and the air flow straightener.



Figure 4. The coaxial fans placed on the top of the flume (a) and the air flow straightener (b).

Beach Slope Model Design and Tests

To model the runup process of waves (all types of waves) one set beach model is constructed. This beach slope model is made as composite bed slopes with three slope transitions. The design of the beach slope model can be seen in **Figure 5**. Before the installment, a set of numerical tests were performed to see the condition of wave breaking under the designed composite bed slopes. The beach slope component is deployed at the other end of the flume, as opposite to the wave/tsunami generators. The material of the slopes is made from steel plates and reinforced with steel frames. This is to prevent the buoyant force of the slope during tsunami/waves experiments that can destabilize the beach slope model. The width of the slope was made 2.45 m to allow some gaps at both edges of the beach slopes. The gaps will later be filled with silicone gel to attach the beach slope structure to both sides of the flume walls.

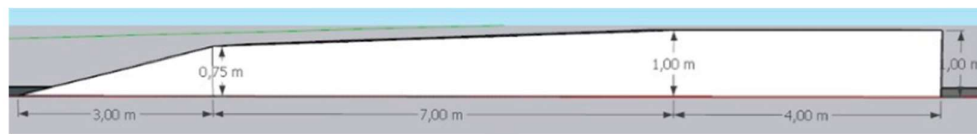


Figure 5. The designed beach slope model with composite slopes to be installed and test for waves/tsunami runup processes.

The waves are expected to break within the second slope. Meanwhile, under tsunami experiments, the tsunami bores can be generated anywhere between the first and the second part of the slope. Runup process is estimated to be occurred within the last 4.0 m of the slope. However, it is difficult to estimate the results of the design based on some empirical formulas as this is a composite slopes model. Most of empirical wave breaking formulas were developed under single beach slope (Wu, 2022). Therefore, a series of numerical models are necessary to estimate the breaking wave locations on the beach slope model. To perform this, DualSPHYsic was used. In the next section, the numerical simulations to predict the breaking wave locations are explained.

DualSPHYsics Simulations

DualSPHYsics is a meshless numerical model developed based on dynamic movement particles of fluid to simulate the hydrodynamic condition of the flow. It is a weakly compressible fluid method adopted by deploying smoothed particle hydrodynamic concept. In the early development of the smoothed particle method in 1977, it had limited applications in the coastal engineering development. Not until early 2005, the method met its momentum due to development of computer hardware and their capacity to simulate large number of particles with reasonable speed (Dalrymple & Rogers, 2006). The method tries to project the movement of fluid particles using Navier-Stokes Equations, where nonlinear effects are taken into account. This weakly compressible computational fluid method could perform well for breaking waves simulation (Altomare, Scandura, Cáceres, A, & Viccione, 2023). Full documentation of DualSPHYsic can be seen at (A. C. Crespo, Dominguez, Barreiro, Gómez-Gesteira, & Rogers, 2011; A. J. C. Crespo et al., 2015)

In this test, we created 2 Dimensional Vertical model (2DV) with the length and the height of the flume as same as the actual size of the TDMRC's flume. Initial water depth inside the flume was set at 1.0 m from the flume's bed. The wave period was 2.0 second with two variation of wave heights, namely 0.4 m and 0.6 m. The size of the particle was 8 mm. With the simulation scenario, there were 511,248 number of particles to be simulated. The simulation was run for about 60 seconds. The water levels along the flume for the first 30 seconds of the simulation can be seen in **Figure 6**.

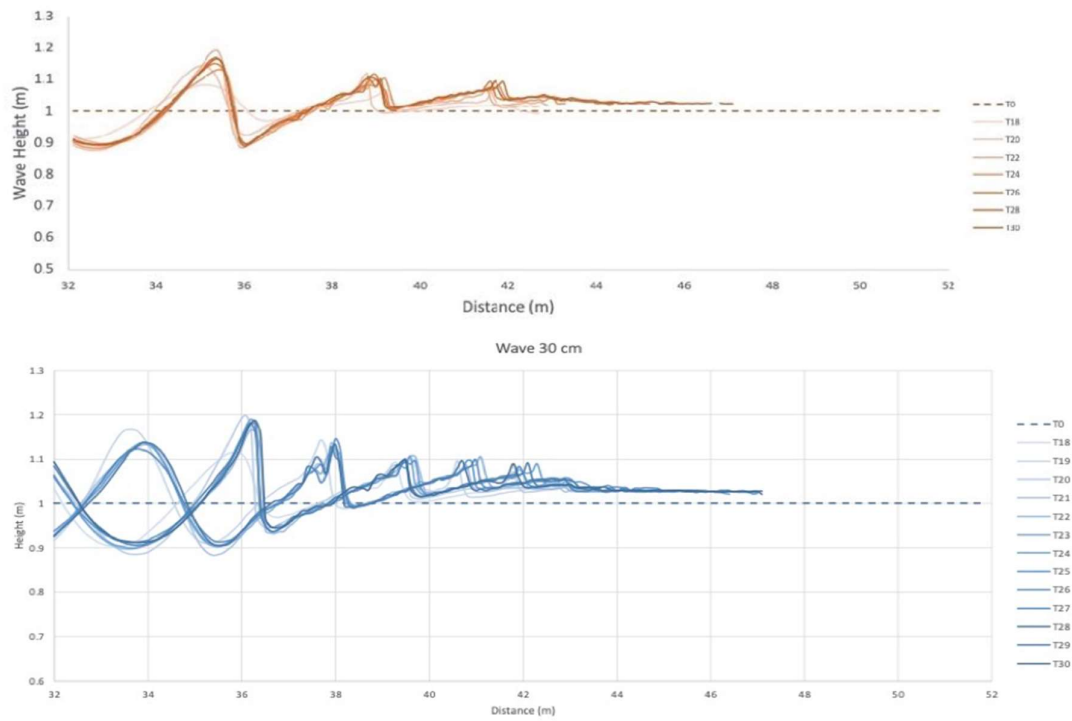


Figure 6. Water level changes from initial start (T0) until 30 seconds after the wave generator started (T30). The distance axis was measured from the wave paddle position; for wave height 0.4 m (upper panel) and 0.6 m (lower panel).

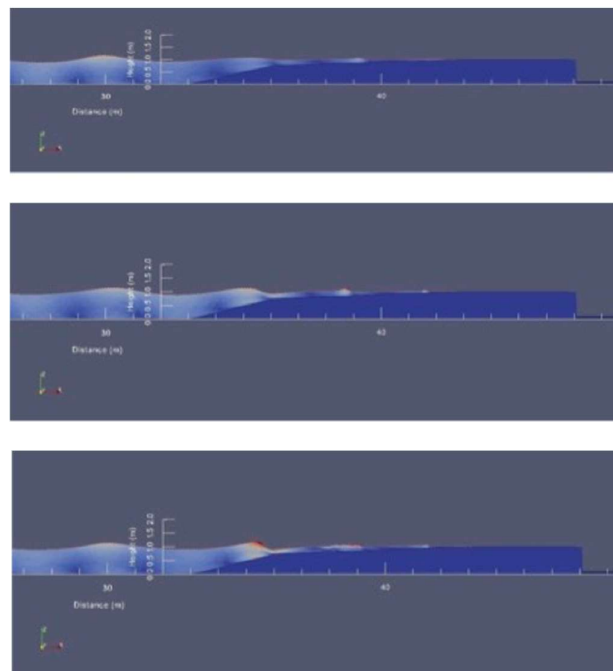


Figure 7. Snap shots of the waves propagation on the composite beach slopes with the offshore waves heights of 0.4 m at 18 s, 20 s, and 22 s, consecutively.

Figure 7 shows the snapshots of the simulation at 18 s, 20 s, and 22 s. The wave will reach its highest level at 22 seconds after the wave generator start and it is located at 35.5 m from the wave paddle. It will break at 39 m from the wave paddle or around the second part of the slopes. These simulations numerically proved that the designed composite beach slopes will be able to generate breaking waves on the slopes. This is important as physical models of wave runup often require wave breaking process to mimic littoral process.

Challenges in the Context of Indonesia

The new completed multi-purposes wave flume facilities give new opportunities for coastal hazard mitigation in Indonesia. The facilities are not only feasible for advanced coastal engineering research topics, but also for educational purposes. The uses of research facilities to promote disaster awareness have been performed at Oregon State University with large flume/basin facilities (Lomonaco et al., 2020). Also at the same university, a much smaller flume was used to increase people awareness on mechanisms of wave runup of visitors (Lyman-Holt & Robichaux, 2013). These best practices can also be followed in running the newly developed multi-purposes wave flume at TDMRC. The multi-purposes flume is potential to use for landslide tsunami experiments, as this flume is equipped with Particle Image Velocimeter Sensors. Also, we have developed the composite slopes where we will be able to tests impacts of tsunamis on buildings, or any onshore structure and to see the reduction effects of mangrove forest to the energy of tsunami wave or wind-driven waves.

The new facilities will indeed require intensive uses and high operational costs. It is apparent that the facilities must be connected with national and local needs in coastal hazards mitigations. So far, this is the only large flume facility that is managed by a university. The other two facilities are run by BRIN and Ministry of Public works as mentioned earlier. Certainly, research at university have a relatively different focus and environment compared to the ministry or agency. Both of the facilities have been long trained to see the needs of the research for real applications. Meanwhile, at university, the issues are rather behind what the ministry/agency performed recently. Fundamental research is more common in universities in Indonesia where limited number of them being continued until real applications. At some cases, there are inconsistencies between global model of education adopted by Indonesian universities and local demands (Beerken, 2010).

Conclusions

The new completed multi-purposes wave flume at TDMRC of Universitas Syiah Kuala has provide new opportunities to develop coastal hazard mitigation measures in the context of Indonesia. With these new advanced facilities, four main scenarios of physical model simulations will be able to be performed namely tsunami, waves, currents, and wind. The designed composite beach slopes are expected to generate wave breaking process at the intermediate slope of the beach model based on DualSPHysic simulation. Real uses of the facilities are among challenges to be answered by Indonesian researchers. As this is one of vital national research facilities, the uses need to be expanded to external parties outside of TDMRC of USK. Furthermore, these facilities can also be functioned as medias to increase community's awareness towards coastal hazards.

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References

- Altomare, C., Scandura, P., Cáceres, I., A, D. A. va. der, & Viccione, G. (2023). Large-scale wave breaking over a barred beach: SPH numerical simulation and comparison with experiments. *Coastal Engineering*, 185, 104362. <https://doi.org/10.1016/J.COASTALENG.2023.104362>
- Arifullah A, Pratama N, Zein I., Nazaruddin, Tarmizi, Ibrahim, and Benazir. (2023). Imaging of Hydrodynamic Field Around Submerged Objects Regular Wave and Tsunami Conditions. *E3S Web Conf.*, 447, 01011, DOI: <https://doi.org/10.1051/e3sconf/202344701011>
- Beerens, E. (2010). Global models for the national research university: Adoption and adaptation in Indonesia and Malaysia. *Globalisation, Societies and Education*, 8(3). <https://doi.org/10.1080/14767724.2010.505099>
- Chandler, I., Allsop, W., Robinson, D., & Rossetto, T. (2021). Evolution of Pneumatic Tsunami Simulators—From Concept to Proven Experimental Technique. *Frontiers in Built Environment*, 7. <https://doi.org/10.3389/fbuil.2021.674659>
- Crespo, A. C., Dominguez, J. M., Barreiro, A., Gómez-Gesteira, M., & Rogers, B. D. (2011). GPUs, a new tool of acceleration in CFD: Efficiency and reliability on smoothed particle hydrodynamics methods. *PLoS ONE*, 6(6). <https://doi.org/10.1371/journal.pone.0020685>
- Crespo, A. J. C., Domínguez, J. M., Rogers, B. D., Gómez-Gesteira, M., Longshaw, S., Canelas, R., ... García-Feal, O. (2015). DualSPHysics: Open-source parallel CFD solver based on Smoothed Particle Hydrodynamics (SPH). *Computer Physics Communications*, 187, 204–216. <https://doi.org/10.1016/j.cpc.2014.10.004>
- Dalrymple, R. A., & Rogers, B. D. (2006). Numerical modeling of water waves with the SPH method. *Coastal Engineering*, 53(2–3), 141–147. <https://doi.org/10.1016/J.COASTALENG.2005.10.004>
- Djalante, R. (2018). Review article: A systematic literature review of research trends and authorships on natural hazards, disasters, risk reduction and climate change in Indonesia. *Natural Hazards and Earth System Sciences*, 18(6). <https://doi.org/10.5194/nhess-18-1785-2018>
- Djalante, R., & Garschagen, M. (2017). *A Review of Disaster Trend and Disaster Risk Governance in Indonesia: 1900–2015*. https://doi.org/10.1007/978-3-319-54466-3_2
- Giridhar, G., & Reddy, M. G. M. (2015). Hydrodynamic Study of Energy Dissipation Blocks on Reduction of Wave Run-up and Wave Reflection. *Aquatic Procedia*, 4. <https://doi.org/10.1016/j.aqpro.2015.02.038>
- Hofland, B., Wenneker, I., & Van Gent, M. (2014). Description of the new delta flume. In *Coasts, Marine Structures and Breakwaters 2013: From Sea to Shore - Meeting the Challenges of the Sea* (Vol. 2, pp. 1346–1355). ICE Publishing.
- Kirby, J. T., Grilli, S. T., Horrillo, J., Liu, P. L. F., Nicolsky, D., Abadie, S., ... Zhang, C. (2022). Validation and inter-comparison of models for landslide tsunami generation. *Ocean Modelling*, 170. <https://doi.org/10.1016/j.ocemod.2021.101943>
- Kuswandi, K. (2023). Physical Modeling of Scouring Around Buildings due to Tsunamis: Generation of Tsunami Using a Limited-Length Flume. In *Tsunamis: Detection Technologies, Response Efforts and Harmful Effects* (hal. 57–68). Diambil dari <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85148253492&partnerID=40&md5=8598b0b8dd6295c3d221fed84944e046>
- Lomonaco, P., Cox, D., Higgins, C., Maddux, T., Bosma, B., Miller, R., & Batti, J. (2020). Building Resilient Coastal Communities: The NHERI Experimental Facility for Surge, Wave, and Tsunami Hazards. *Frontiers in Built Environment*, Vol. 6. <https://doi.org/10.3389/fbuil.2020.579729>
- Løvholt, F., Glimsdal, S., & Harbitz, C. B. (2020). On the landslide tsunami uncertainty and hazard. *Landslides*, 17(10). <https://doi.org/10.1007/s10346-020-01429-z>
- Lyman-Holt, A. L., & Robichaux, L. C. (2013). Waves of engineering: Using a mini-wave flume to foster engineering literacy. *ASCE Annual Conference and Exposition, Conference Proceedings*. <https://doi.org/10.18260/1-2--22747>
- McGovern, D. J., Robinson, T., & Rossetto, T. (2016). Experiments on Tsunami Impact with a Vertical Sea Wall. In *1st International Conference on Natural Hazards & Infrastructure*.

- Meilianda, E., Mauluddin, S., Pradhan, B., & Sugianto, S. (2023). Decadal shoreline changes and effectiveness of coastal protection measures post-tsunami on 26 December 2004. *Applied Geomatics*. <https://doi.org/10.1007/s12518-023-00514-x>
- Schimmels, S., Sriram, V., & Didenkulova, I. (2016). Tsunami generation in a large scale experimental facility. *Coastal Engineering*, 110. <https://doi.org/10.1016/j.coastaleng.2015.12.005>
- Shimosako, K., Takahashi, S., Suzuki, K., & Kang, Y. (2002). Large Hydro-Geo Flume and its Use for Coastal Engineering Research. *Technical Note of National Institute for Land and Infrastructure Management*.
- Spencer, T., Möller, I., Rupprecht, F., Bouma, T. J., van Wesenbeeck, B. K., Kudella, M., ... Schimmels, S. (2016). Salt marsh surface survives true-to-scale simulated storm surges. *Earth Surface Processes and Landforms*, 41(4). <https://doi.org/10.1002/esp.3867>
- Triatmadja, R., Rahardjo, A. P., & Yuwono, N. (2019). The behavior of a tsunami-like wave produced by dam break and its run-up on 1:20 slope. *Science of Tsunami Hazards*, 38(2), 49–67. Diambil dari <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85073407993&partnerID=40&md5=d97b4e5dfca6e9fd072a2bb81e401706>
- Triatmadja, R., Yuwono, N., & Nurhasanah, A. (2020). Tsunami force on low building and the effect of surrounding buildings. *Proceedings of the 7th International Conference on Asian and Pacific Coasts, APAC 2013*, 509–514. Diambil dari <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85086072694&partnerID=40&md5=23697cdbe403efb62f35728474fd7b30>
- Wu, Y. T. (2022). Modeling the Evolution and Runup of Breaking Solitary and Solitary-Like Waves on Straight and Composite Slopes. *Journal of Earthquake and Tsunami*, 16(6). <https://doi.org/10.1142/S1793431122410032>
- Ziana, Z., Azmeri, A., Yulianur, A., & Meilianda, E. (2022). The eco-hydraulics base as flood mitigation to overcome erosion and sedimentation problems: A case study in the Lae Kombih River, Indonesia. *Journal of Water and Land Development*, (55). <https://doi.org/10.24425/jwld.2022.142326>