Graduate School of Creative Science and Engineering
Waseda University

博　士　論　文　概　要
Doctoral Dissertation Synopsis

論　文　題　目
Dissertation Title

Numerical Modelling of Flood Forces due to Storm Surges

高潮氾濫時の流体力評価の数値モデル

申　請　者
(Applicant Name)
Justin Joseph Panlilio VALDEZ
ヴァルデス　ジャスティン　ジョセフ　パンリリオ

Department of Civil and Environmental Engineering, Research on Coastal Engineering and Management

February, 2023

The Philippines is an archipelago country situated on the Northwest Pacific Basin, and its location is unfortunate in terms of the pathways of typhoons, which can cause massive damage to structures due to severe winds and storm surges. Perhaps the most significant Philippine storm surge event in recent history was from Typhoon Haiyan in 2013, which brought surges of around 5-6 meters at Tacloban City in Leyte and caused extensive damage to structures and deaths of up to thousands. To understand the likely impacts that would be exerted by a storm surge on a structure deemed important (such as a school) the authors used an integrated weather-surge-structure model that hindcasted the flooding that took place during. The primary aim of this dissertation is to clarify the importance of considering flood loads when designing structures against significant storm surge events, compared with other design loads such as wind loads, by using numerical simulations. Chapter 1 provides an introduction of this study, including the motivation of this research that arose from the Typhoon Haiyan storm surge event. Since it is difficult to provide an accurate estimation of the effects of wind and flood loads generated by a strong typhoon and storm surge, an integrated weather-surge-structure model to solve this is proposed. This chapter also introduces two more tropical cyclone cases: the 2021 Typhoon Rai in the Philippines and the 2022 Cyclone Batsirai in Mauritius.

Chapter 2 is dedicated to the literature review for this dissertation. First, the events during the three typhoon case studies (Typhoon Haiyan, Typhoon Rai, and Cyclone Batsirai), including related post-disaster field surveys and numerical modelling from other researchers, are discussed. For the Typhoon Haiyan case, the intensity and track of the typhoon, and the shallow bathymetry of the bay resulted in Haiyan being able to push a significant amount of water from the south towards Tacloban and nearby towns. Due to the significant damage brought by the strong winds and surge, the National Structural Code of the Philippines (the design code of the country) was updated. However, flood loads are still not usually used in design of new structures, such as the public school buildings in the country. Next, the models used in simulating typhoons and storms surges are discussed at the end of this Chapter 2 and continued to the numerical methodology in Chapter 3. The coupled model included the use of the Weather Research and Forecasting (WRF) Model to simulate the atmospheric conditions during the passage of Haiyan, the Finite Volume Coastal Ocean Model (FVCOM) to simulate the storm surge and obtain the boundary conditions for the wind and flood (hydrostatic, hydrodynamic, and breaking wave), and the Structural Analysis and Designing Program (STAAD.Pro) to calculate the corresponding axial, shear, and bending moment envelopes based on the storm surge simulation. To improve the typhoon modelling, particularly the track, the Tropical Cyclone Bogussing (TC-Bogus) scheme was used. A 4-floor public school building in Tacloban was modeled and the effects that the storm surge would have on a corner column were analyzed.

Chapter 4 provides the results of the weather-surge-structure numerical modelling for the three tropical cyclone cases. The hindcast numerical simulation was performed using the TC-Bogussing scheme in the WRF model, which showed good agreement with observation data. Thus, the simulated central pressure, wind speed, and track of Typhoon Haiyan was used as input in the storm surge simulation. In the FVCOM model results, observations from 3 post-disaster field surveys were used for validation, and the simulation showed good agreement around Tacloban area, though the accuracy of the estimation of inundation levels decreased with distance from this city. The time-series of flood simulation data at Panalaron Central School in downtown Tacloban was used as inputs for the wind and flood (hydrostatic, hydrodynamic, and breaking wave) loads, which were analyzed using STAAD.Pro model. Based on the structural analysis results, the axial, shear, and moment at the corner column significantly increased when considering flood loads, indicating the importance of including such loads in the design of essential structures.

To demonstrate its versatility, the weather-surge-structure model was then used simulate two more tropical cyclone cases: the 2021 Typhoon Rai in the Philippines and the 2022 Cyclone Batsirai in Mauritius. Typhoon Rai hit the central Philippines and reportedly brought storm surges in Cebu and Bohol. To verify that storm surges occurred in the area and explain the watermark levels from a field survey, the same weather-surge model was used at Tubigon, Bohol and nearby islands of Batasan, Ubay, and Pangapasan. Additionally, the wind waves were included in the hydrodynamic modelling.

In the WRF Typhon Rai modelling, there was a slight deviation in the simulation central pressure, due to the difficulty of simulating a typhoon over the hilly topography of Bohol. Nonetheless, the wind speeds were simulated well during its peak. There was also a slight deviation of 15 km northward in the simulated track. Overall, the simulated pressure, wind, and track were deemed acceptable for the storm surge simulation. In the FVCOM-SWAVE modelling, the results verified that there was a surge that occurred in Tubigon, and high wind waves were experienced. The numerical model was able to explain the main factors influencing the measured watermarks at Bohol from Typhoon Rai. Next, the challenges of simulating Cyclone Batsirai over the Indian Ocean are explained.

Chapter 5 provides the discussion and explanation of the simulation results and the importance of the proposed numerical methodology. As coastal engineers, it is very important to know whether a storm surge or high wave attack occurs when a typhoon hits a vulnerable area. As noted in the conclusion in Chapter 6, the importance of the integrated weather-surge-structure numerical methodology in understanding the typhoon and storm surge phenomena and the resulting driving forces are emphasized in this study so people can build back better. The methodology is flexible, meaning it can be applied to any typhoon, at any location, and at any structure, so it is recommended to be applied in the Philippines wherein typhoons are frequent and flood forces are not included in design of structures. Overall, an integrated weather-surge-structure model using WRF, FVCOM, and STAAD.Pro was able to accurately simulate Typhoon Haiyan, its storm surge at Tacloban, and evaluate the wind and flood forces on a public school building. The performance of the model was also shown in the simulation of Typhoon Rai and Cyclone Batsirai.

List of research achievements for application of Doctor of Engineering, Waseda University

Full Name： Valdez　Justin Joseph Panlilio　　seal or signature

Date Submitted(yyyy/mm/dd): 2023/2/3

種類別 (By Type)	題名、　発表・発行掲載誌名、　発表・発行年月、　連名者（申請者含む） (theme, journal name, date & year of publication, name of authors inc. yourself)
Journal	**O Valdez J.**, Shibayama T., Takabatake T., and Esteban M. 2022. "Simulated flood forces on a building due to the storm surge by Typhoon Haiyan". Coastal Engineering Journal. doi: 10.1080/21664250.2022.2099683.
Journal	**O** Esteban M., **Valdez J.**, Tan N., Rica A., Vasquez G., Jamero L., Valenzuela P., Sumalinog B., Ruiz R., Gera W., Chadwick C., Sparatu C., and Shibayama T. "Field Survey of 2021 Typhoon Rai – Odette- in the Philippines". Journal of Coastal and Riverine Flood Risk, 1. doi: 10.48438/jcrfr.2023.0001.
Journal	Ngo P., Garciano L., De Leon M., Lopez, N., Ishii H., Iimura K., **Valdez J.**, and Shibayama T. 2022. "Experimental and Numerical Modelling of a Tide Embankment Section in Tacloban City, Philippines subjected to Storm Surge". Natural Hazards Review, 23(4). doi: 10.1061/(ASCE)NH.1527-6996.0000575.
Journal	Takabatake T., Han D., **Valdez J.**, Inagaki N., Mäll M., Esteban M., and Shibayama T. 2021. "Three-Dimensional Physical Modelling of Tsunamis Generated by Partially Submerged Landslides". Journal of Geophysical Research, 127(1). doi: 10.1029/2021JC017826.
Journal	Takabatake T., Mäll M., Esteban M., Nakamura R., Thit Oo Kyaw, Ishii H., **Valdez J.**, Nishida Y., Noya F., and Shibayama T. 2018. "Field Survey of 2018 Typhoon Jebi in Japan: Lessons for Disaster Risk Management". Geosciences, 8(11), 412. doi:10.3390/geosciences8110412.
Journal	**O** Tajima Y., Yasuda T., Pacheco B., Cruz E., Kawasaki K., Nobuoka H., Miyamoto M., Asano Y., Arikawa T., Ortigas N., Aquino R., Mata W., **Valdez J.**, and Briones F. 2014. "Initial Report of JSCE-PICE Joint Survey on the Storm Surge Disaster Caused by Typhoon Haiyan". Coastal Engineering Journal, 56(1), 14500061-12. doi:10.1142/S0578563414500065.
Conference	**O Valdez J.** and Shibayama T. 2023. "The role of numerical modelling of typhoons and storm surges in building back better", 10th International Conference on Coastal and Port Engineering in Developing Countries, Manila, Philippines. (Peer reviewed; oral presentation; set on October 9-13, 2023).
Conference	**O Valdez J.**, Shibayama T., and Esteban M. 2022. "Identification of Potential Storm Surges due to Typhoon Rai Using Numerical Models", 2022 International Conference on Coastal Engineering, Sydney, Australia. (Peer reviewed; poster presentation; presenter).
Conference	**O** Esteban M., **Valdez J.**, Jamero L., Tan N., Rica A., Valenzuela P., Ruiz R., Sumalinog B., Vasquez G., Chadwick C., and Shibayama T. 2022. "Survey of Storm Surge due to Typhoon Rai in December 2021 in the Philippines". Oral Presentation, 2022 International Conference on Coastal Engineering, Sydney, Australia. (Peer reviewed; oral presentation; presenter).
Conference	**O Valdez J.** and Shibayama T. 2020. "Analysis of a School Building against Typhoon Haiyan Storm Surge Forces". In Lynett P. (Ed), Proceedings of virtual Conference on Coastal Engineering, 2020. doi:10.9753/icce.v36v.waves.12. (Peer reviewed; oral presentation; presenter).