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# Review of

### Doctoral Dissertation written by Parisa Radan

## Wind Effect on Ice Dynamics

### 1. Formal and legal basis

The formal basis for preparing the review is the invitation letter written by prof. dr hab. inż. Ewa Wojciechowska, the Dean of the Faculty of Civil and Environmental Engineering at Gdansk University of Technology (I.dz. 48/WILiŚ/2025). The evaluation was conducted based on the doctoral dissertation prepared in English by the PhD Candidate, Ms. Parisa Radan. The research was supervised by dr hab. inż. Tomasz Kolerski, prof. PG, from the Department of Geotechnical and Hydraulic Engineering at Gdansk University of Technology. The dissertation was submitted in both paper and digital forms to the Council of the Discipline of Civil Engineering, Geodesy, and Transport at Gdansk University of Technology on December 23, 2024. The review was conducted in accordance with the requirements outlined in Article No. 187 of the Act on Higher Education and Science of July 20, 2018 (POL-2018-R-109017), as amended by subsequent regulations (POL-2018-R-109019).

### 2. Overview of the conducted research

The main area of the presented study is the behavior of ice cover in surface waters, including inland reservoirs, gulfs, lagoons, and open seas. The effort is focused on the movement of ice cover and ice floes caused by wind. The fundamental assumption behind the conducted research is the stationarity of water in the reservoir. The research has two explicit purposes, as stated in the first chapter, the Introduction. The first is the experimental analysis of the impact of wind velocity on ice movement. The main focus is on the drag force and ice velocity. The second purpose is to implement the numerical model for simulating ice movement, thereby proving the usefulness and applicability of the relationship discovered in the laboratory. From a theoretical perspective, the conducted investigations may enhance and expand our understanding of ice processes, as well as provide more information on the mechanics of ice transport in surface waters. Considering the current state of the art in the field of ice processes, the presented research may support ongoing scientific efforts and help fill existing knowledge gaps. On the other hand, the relationship between wind and ice velocities is fundamental for predicting and preventing tensions caused by ice on structures such as dams, dikes, weirs, and gates. Hence, the importance of the presented research is, in my opinion, unquestionable.

The central part of the research is based on advanced and sophisticated laboratory experiments conducted at the Institute of Hydro-Engineering of the Polish Academy of Sciences (IHE PAS). The PhD Candidate applied Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV) techniques and image analysis methods for detailed determination of wind and ice velocities. To avoid problems with maintaining specific temperature conditions, propylene pallets of defined sizes were used. Such an advanced approach enabled the observation and measurement of spatially variable distributions of wind and ice velocities. Then, the computer model DynaRICE was applied to simulate ice movement. The first information about the model was published in the International Journal of Offshore Engineering by Shen and co-authors in 1993. From the very beginning, the applied concept was based on Lagrangian methods of particle tracking, as explicitly mentioned in the dissertation Smoothed Particles Hydrodynamics (SPH). Currently, this is one of the most advanced methods for the simulation of fluids and moving bodies, especially easily applied in the field of fluid-structure interaction. The DynaRICE model has been actively developed since its first publication. In the presented research, the model is used for comparison with the physical model experiments. Then, the calibration of the wind drag coefficient was conducted. This step enabled the implementation of the model in two real cases: the ice tensions on the photovoltaic structure in Łapino reservoir and the formation of the polynya in the Vistula Lagoon. It must be acknowledged that such a research plan is correct, the applied methods are advanced, and the entire procedure ensures that the defined purposes are achieved.

## 3. Analysis of the dissertation

The submitted dissertation comprises eight regular chapters, two appendices, two versions of the abstract and keywords in English and Polish, acknowledgements, and references, all presented as separate sections. There are also added formal statements. The dissertation comprises 75 figures, 11 tables, and 41 equations. The list of symbols is located in Appendix B. If the lists of figures and tables were also added, it would increase readability and make reviewing easier. There are 100 references, including 77 papers in scientific journals, five books, 13 conference papers, and five reports. All references in the list are mentioned in the text. Missing references were not detected.

Chapter 1, entitled "*Introduction,*" is divided into two subchapters: "*1.1 Objectives of the study*" and "*1.2 Motivation behind the study*." In the first part, The PhD Candidate precisely designs the aims and scope of the research. The description begins with an indication of the central area of interest, which is an investigation of the wind impact on the drift of surface ice. Then, two specific purposes are defined with a broader explanation. In this part, the implemented methods are also mentioned. As a result, this part of the text serves as the research scope. In the second part, the PhD Candidate provides motivation for the investigations, referencing historical examples from Polish ice-jam floods and scientific literature on the subject.

In Chapter 2, entitled "*Literature review*", the references related to the research area are presented and briefly analyzed. The chapter includes three subchapters, which are "*2.1 River ice processes,*" "*2.2 Laboratory experiments of river ice dynamics,*" and "*2.3 Mathematical modeling.*" In general, there are 71 quotations related to subjects fundamental to the presented research. The mentioned references include 56 papers from well-recognized journals, one book, three reports and manuals, and 11 conference papers. In general, the chapter demonstrates a sufficient understanding of the subject being investigated. The mentioned references are a reasonable basis for the conducted research.

The third chapter, entitled "3*. Methodology*," is divided into two parts located in separate subchapters. The experimental part is described in the subchapter "*3.1 Description of the laboratory simulation and physical modeling.*" The second subchapter, "*3.2 Mathematical model of wind to ice interaction,*" focuses on mathematical modelling. In the first part, the organization of experiments in the wave flume at the Institute of Hydro-Engineering of the Polish Academy of Sciences (IHE PAS) is explained. In the chapter, some of the base assumptions are provided, such as the stationarity of the water, the composition and interpretation of the pieces, and which ice formation processes were neglected in the study, among others. In the reviewer's opinion, the list of fundamental assumptions is longer; however, this issue is addressed in the section of remarks. An interesting innovation is the utilization of water droplets as seeding particles for PTV scanning. In the second part, the chosen mathematical model, namely DynaRICE, is presented. The main basis of the model is the so-called Lagrangian Discrete Particle method, which originates in Smoothed Particles Hydrodynamics (SPH). The model is completed with laws and formulas describing wind-ice and ice-water interactions. In my opinion, the wide range of different methods applied in the research is impressive, but it is fully justified by the complexity of the problem analyzed. However, the readability of this large chapter could be increased by introducing a single flowchart that illustrates the interconnections between different elements of the research and the exchange of data and results between various stages of the investigation.

The following three chapters present the results obtained at various stages of the investigation. These are "*4. Analysis of the physical model study results*", "*5. Implementation of the physical model results into the mathematical model*", and "*6. Model calibration with the real case scenarios*." In the first of these, the experimental results are presented in three subchapters related to (1) PIV measurements of wind and water velocities, (2) verification of the PIV measurements using an anemometer device, and (3) PTV measurements of ice velocity. The results are presented in various graphs, ranging from pure vertical profiles and bar plots to more complex swarm plots, velocity maps, and 3D visualisations of variability in the velocity components. Deeper care should be taken in the choice of graph scales to ensure that similar graphs are easily comparable. The next chapter presents the initial setting of the simulation model, DynaRICE. Primarily, the model was configured to reconstruct the conditions observed in the laboratory. The results presented in this chapter can be divided into two significantly different parts. Initially, the model is applied without calibration. The second part presents the calibration of the wind-ice drag coefficient. The analysis is done under the assumption of the logarithmic profile. In the reviewer's opinion, the assumption of the equivalence between ice floes and propylene pallets, even if it is common practice, should also be written explicitly. The issue is explained in the remarks. Finally, the dependence of the drag coefficient on the wind velocity was detected. Chapter 6 presents two interesting real cases. These are (1) the analysis of ice pressure on photovoltaic structure in the Łapino reservoir and (2) the movement of ice in the Vistula Lagoon with the formation of polynya. The model proved its usefulness, and the results show good agreement with available measurements. However, the calibration of the model in a laboratory environment and its application in real cases always raise questions about scale effects, e.g., differences in the thickness of ice sheets. The presented analysis could be further developed by recalculating the wind velocity from the laboratory conditions to those of real cases based on reasonably chosen similarity criteria.

Although the next chapter, "*7. Summary of the results*," is composed differently, it serves as the discussion. This part also contains a substantial number of processed results, which is an extension of the analysis of the results. At the end of the chapter, the pivotal elements of the research are presented as a list of 19 points. Unfortunately, the chapter does not include comparisons with other results reported in the scientific literature.

The final chapter, "*8. Conclusions*," nicely summarizes the work carried out. The choices made in the investigations are correct, and the results provided are valid. The purposes of the research, defined in the Introduction, are satisfied. Between achievements of the presented study, the three below may be emphasized:

- Detailed analysis of air and water velocity distributions obtained due to the application of advanced measurement technologies. Some difficulties were overcome with the PhD Candidate's inventions, such as the seeding of water droplets in wind velocity measurements. In other cases, detailed image analysis supported the measurements.

- Modeling of the ice movement with very sophisticated and advanced DynaRICE software. The calibration of the model enabled the preparation of the model application in real cases. During this process, the dependence of the wind drag coefficient on the wind velocity was detected.

- Application of the model to real cases, which demonstrates the practical usefulness of the conducted laboratory experiments. The PhD Candidate presented how to effectively apply the investigated concepts to solve frequently encountered engineering problems.

It would be a good idea to include comments on the significance of the achievements for both science and practice, as well as the limitations of the current study and potential future developments.

Generally, the dissertation differs slightly from the standard format, which typically includes an Introduction, Materials and Methods, Results and Discussion, and Conclusions. Instead, the introductory part is presented in two chapters; materials and methods are described in a single chapter, but the results, including elements of discussion, are shown in three chapters or even four chapters. As mentioned, the entire presentation is brought to a close with conclusions. In general, the components necessary to understand the research concept are described sufficiently. The language used is correct and clear, and the explanations of the steps done and procedures implemented are comprehensive. Although the composition of the dissertation could be different, the complexity of the research and the involvement of multiple distinct methods justify the narrative approach adopted by the PhD Candidate.

## 4. Remarks and questions

Major remarks and questions

(A) The title of the dissertation, "*Wind effect on ice dynamics*", is very general and broad. The presented research is extensive, but the title could be more specific. E.g. "*The experimental and numerical analysis of surface ice movement induced by the wind stress.*"

(B) The "*1. Introduction*" consists of elements necessary for the definition of the scientific problem. After reading this part, it is understandable what is the current state-of-the-art in the investigated field, and the scientific gap is identified correctly. The importance of the problem is also evident. The purposes are precisely defined, and the scope of the research is also briefly outlined. However, the definition of the problem could be completed with some hypotheses lying behind the research, which could support the formulation of the conclusions.

(C) In fact, the experiments described in the dissertation are not carried out with ice. The PhD Candidate wisely avoided all the problems related to preserving the specific local climate in the laboratory. Instead, the proper material was chosen – propylene. Supposedly, the choice of material was inspired by a literature study. There is an appropriate quotation, namely Wang et al. (2016). Theoretically, the PhD Candidate could assume that this approach, as proven in other scientific publications, is widely accepted and understandable. However, the choice of the material is crucial to the validity of the provided results. It is not so apparent to the broader audience. It may constrain the conclusions drawn, e.g. differences in surface roughness, lack of damages caused by crashing, etc. In my opinion, the assumptions lying behind the choice of material could be stated explicitly in the dissertation.

(D) Another element that requires more awareness is the similarity between laboratory experiments and real cases in terms of specific dynamic criteria. The thickness of the ice pieces in the laboratory is 1 cm, whereas the average thickness of the ice cover in the Łapino reservoir is approximately 15 cm. If the coefficient of wind drag is calibrated in the laboratory but implemented in the natural environment, the wind velocities should be comparable according to some physical criteria. Such criteria are provided in one of the references quoted by the PhD Candidate, namely Zufelt and Ettema (1996). However, the derivations introduced there could be applied to the cases analyzed in the dissertation.

(E) In my opinion, the classical Discussion based on the comparison of the obtained results with other results presented in the scientific literature could increase the importance of the presented results. Such discussion may highlight the uniqueness of the carried-out investigations and lead to an understanding of its strengths and weaknesses. It may also indicate the ways for further developments.

(F) Although the importance of the study is beyond doubt, the last chapter, "*8. Conclusions*." could include a short analysis of the study's impact on science and practice. Such an impact should be analyzed concerning the specific field of ice science, but it should also be presented in the broader context of water management, marine science, river engineering, and other related disciplines.

Detected problems and incorrections

(1) There are a few incomplete quotations detected. The pages where such a problem exists are 14, 19, 23, 27, and 28.

(2) The formatting of the figures needs improvement. In many cases, the descriptions of the axes and legends are too small. In some cases, the figures are spread over two pages. The ranges of values applied to the axes must be compatible with the plots to be compared. These problems are related to all the Figures from 4-1 to 4-9, as well as to Figures 4-21, 5-1, 5-2, 5-8, 5-14, 6-5, 7-1, and 7-2.

(3) It is not known what is the role of Figures 4-11 to 4-19, as well as Figures 4-20 and 4-21. The results of the first group are summarized in Table 4-2. The second group is presented in Table 4-3. In my opinion, it would be better to show one example and explain the rest in the Tables.

(4) It is hard to understand why nonlinear trend lines are applied in some of the plots. It appears in Figures 5-10, 7-1 and 7-2. In my opinion, all presented data could be smoothed with linear equations.

(5) The text should be carefully checked, taking into account both clarity and understandability. Some of the sentences should be rewritten, e.g. on page 12, "*There are also following <u>advantageous</u> in the stimulated cover formation, such as, prohibition of ice jam formation downstream of the reservoirs, and the jam formation at the spillways*."; on page 17, "*For the fatigue estimations. They combined wind, wave, and ice loads, using simulated analysis of time-series of the various loads*." In other cases, more precise terminology should be used. For example, on page 9, the term "*physical model*" should be replaced with "*physically-based model.*"

(6) There are small mistakes detected in some of the figures, e.g. the description in Figure 3-18 seems to be incorrect because part (a) shows the greatest density, while part (b) includes the smallest number of pieces; in Figure 3-25 the density of the velocity vectors is also problematic because the presented velocities are denser than the simulated particles; in Figure 5-1 the sizes of the ice pieces are different than the pieces of the ice analyzed in the laboratory.

(7) Some passages suggest that a brief explanation of the SPH method is needed. For example, on page 72, the term "*smoothing length*" appears; on page 73, the setting of the boundary conditions is specific for the SPH method.

## 5. Final evaluation of the dissertation

Taking into account the complexity of the problem, the approach adopted by the PhD Candidate can be considered reasonable. In general, serious errors were not detected. The research problem was defined correctly. Its importance is beyond doubt, and the applied methods are advanced and consistent with the current state of the art. The adopted approach is original and innovative. The results are valuable both theoretically and practically.

Considering the entire work and its potential impacts, the precise formulation of primary assumptions is crucial. In the reviewer's opinion, these are (1) water is stationary without significant impact of inflow and outflow, (2) only the surface forms of ice are considered, (3) propylene can be treated as equivalent of ice in the temperatures of liquid water, (4) coefficient of the wind drag calibrated in the laboratory can be implemented in the real case conditions. The first two are explained in the text. Although the next two are not mentioned explicitly, correct quotations are provided. Understandably, the PhD Candidate could assume that these approaches are standard practice in the field of ice investigations.

It is essential to highlight that the investigated subject is significant and has a profound impact on other areas of scientific research and practice. The importance of the ice behavior for the stability of the engineering structures was presented in the text with two illustrative examples. Essentially, the analyses contribute to the understanding of river and reservoir flow processes. These may also impact the modelling of the mass and energy transport processes in rivers and reservoirs.

**6. Conclusions**

Overall, the doctoral dissertation is a valuable contribution to research on ice processes in surface waters. The potential application of the achieved results was proved in the dissertation. The PhD Candidate has demonstrated his substantive knowledge and a good knowledge of professional literature in formulating the goals of the work. The PhD Candidate also shows well that she is an independent researcher.

The PhD thesis of Ms. Parisa Radan meets all the requirements for doctoral dissertations by the Act of 20 July 2018 Law on Higher Education and Science. Considering my positive assessment, I am applying to the Scientific Council of the Discipline of Civil Engineering, Geodesy and Transport Chairman for admission to Ms. Parisa Radan to the next stages of the doctoral dissertation.

Tomasz Dysarz