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REVIEW

of doctoral dissertation of Ms Parisa Radan entitled

"Wind effect on ice dynamics"

for the purpose of awarding the academic degree of Doctor in the field of engineering and technical sciences, in the scientific discipline of Civil Engineering, Geodesy and Transport

FORMAL BASIS FOR CONDUCTING THE REVIEW

This review has been written at the request of the Dean of the Faculty of Civil and Environmental Engineering at Gdańsk University of Technology, Professor Ewa Wojciechowska, DSc, PhD, Eng. (document no. I.dz. 49/WILiŚ/2025 dated 20 January 2025).

The evaluation has been carried out in accordance with the provisions of the Act of 20 July 2018, "Law on Higher Education and Science", Journal of Laws of 20 April 2023, item 742, as amended; Chapter 2 "Doctoral Degree" ("Prawo o szkolnictwie wyższym i nauce" (Dz.U. z dnia 20 kwietnia 2023 r., poz. 742, z późn. zm.; rozdz. 2 "Stopień doktora").

GENERAL INFORMATION

The doctoral dissertation entitled "Wind Effect on Ice Dynamics" was prepared at the Department of Geotechnics and Hydraulic Engineering, Faculty of Civil and Environmental Engineering, Gdańsk University of Technology. The supervisor of this dissertation is Tomasz Kolerski, DSc, PhD, Eng., Associate Professor at Gdańsk University of Technology.

The doctoral dissertation submitted for evaluation by Ms. Parisa Radan is a typical scientific work comprising a total of 161 pages (A4), written in English. The dissertation has been enriched with 11 tables and 155(!) figures, 33 of which are photographs, while the remaining 122 are various types of charts, diagrams, and numerical visualizations.

The dissertation is structured into 8 main chapters with subsections. The chapters are as follows: 1) Introduction, 2) Literature review, 3) Methodology, 4) Analysis of the physical model study results, 5) Implementation of the physical model results into the mathematical model, 6) Model calibration with the real-case scenarios, 7) Summary of the results, and 8)

Conclusions. The dissertation also includes summaries in both Polish and English, as well as 2 appendices. Appendix A illustrates "The wind velocity fields for two or three working fans", while Appendix B provides an explanation of the symbols used in the dissertation.

The list of references at the end of the dissertation comprises a total of 100 references, including 2 publications co-authored by the Doctoral Candidate. The source materials and literature reviewed have been appropriately selected and used. They are up-to-date and all pertain to the subject matter addressed in the dissertation. I also confirm that Ms. Parisa Radan fulfils the formal criteria concerning the structure and format of the submitted doctoral dissertation.

OVERVIEW AND EVALUATION OF THE DISSERTATION

Numerous studies have documented the detrimental effects of ice on hydraulic and energy infrastructure, navigation, and water management in reservoirs and river channels. Therefore, the scientific understanding of ice phenomena dynamics due to wind, and the determination of its key parameters are crucial for the development of an effective and reliable numerical model for predicting the influence of wind forces on the ice floe or ice cover, as well as simulating its drift. On the other hand, from a practical standpoint, scientists and technicians are expected to offer simple (ready for practical use) procedures and computational tools, such as software for the "wind-ice" relationship. Therefore, the research topic undertaken in the dissertation should be considered highly relevant, up-to-date, and needed, as it concerns a scientifically engaging and practically significant issue. I also believe that the title of the dissertation is appropriate and fully in line with its content.

Right at the beginning of the dissertation (in Chapter 1), Ms Radan has outlined her two primary research goals:

1. to experimentally investigate the phenomenon of ice drift due to wind in a laboratory setting;
2. to use the DynaRICE model for computer simulations of real-world scenarios of wind impact on ice in water bodies (although I believe, that in this form the research task is actually to verify the application potential of DynaRICE).

The literature review outlined in Chapter 2 offers a detailed introduction to the dissertation's topic and summarizes the current state of knowledge, including mathematical modelling and research reports using models such as DynaRICE. Also, a more detailed description is given here of modern non-invasive measurement techniques, namely PIV (Particle Image Velocimetry) and PTV (Particle Tracking Velocimetry). These techniques are used later on in the research: PIV for measuring the velocity field of both water and wind, and PTV for measuring the velocity of drifting ice.

Not only the methodology, but also the scope of the research is noteworthy, and both are described in great detail in Chapter 3, along with the research material. The following topics are covered: 1/ Laboratory simulation and physical modelling (including the experimental set up; PIV description and the description of experiments related to wind velocity on ice), and 2/ Mathematical model of wind to ice interaction (including the formulation of the wind to ice interaction used in DynaRICE and the DynaRICE simulation of the ice process related to the wind velocity on ice).

Below are other details: Laboratory experiments were conducted in a specially adapted straight water flume (research section length: 3.95 m, width: 0.6 m, water depth: 0.595 m). To capture the influence of wind alone on ice drift, the water in the flume was still. At a height of 20 cm above the water surface, a sealed ceiling with a measurement window was installed, creating a wind tunnel with a wind generator at the inlet. The generator consisted of three fans, which were turned on sequentially to create three different wind fields. The averaged wind speeds were approximately 0.5; 1.2 and 1.5 m/s. Rectangular polypropylene pallets were used as a substitute for ice. They had a constant thickness of 1 cm, and a density similar to that of natural ice. Two types and sizes of ice were considered: ice pieces (floe) measuring 10×10 cm and ice covers measuring 40×60 cm. In the case of ice pieces, also the concentration was variable: low (0-0.35), medium (0.35-0.7), and high (0.7-1). For three different wind fields, the average drift velocities of the ice pieces ranged from 0.019 to 0.026 m/s for one operating fan; from 0.029 to 0.035 m/s for two fans; and from 0.035 to 0.041 m/s for three operating fans, depending on ice concentration. On the other hand, the average drift velocities of the ice cover, for two and three operating fans, were 0.0195 and 0.0265 m/s, respectively.

In adapting the DynaRICE model and conducting simulations for two selected real-world sites (the Łapino Reservoir and the Vistula Lagoon), hydrological and meteorological data from field measurements were used. Results of Ms Radan's own laboratory tests (e.g. wind velocity and ice concentration) served as input data for the numerical model.

The Doctoral Candidate's modern and comprehensive scientific toolkit is commendable. She conducted multi-variant laboratory measurements, performed computer simulations, and analysed the results using advanced research tools such as the aforementioned PIV and PTV. She also made use of several software packages including LaVision DaVis, PTVlab, MATLAB, and DynaRICE.

Results of this research, along with the discussion, are presented in detail in Chapters 4 through 7. These results primarily consist of graphs of the processed measurement and calculation results, as well as visualizations from computer simulations.

In evaluating the dissertation, it should be emphasized that the Doctoral Candidate has undertaken a very significant research effort. The scope of the work carried out is extensive, by which I mean: the construction of a laboratory model, calibration of the measurement equipment, numerous series of measurements, repetition of measurements, data processing, statistical analyses of results, adaptation of the numerical module, and DynaRICE computer simulations, including a real-case study for two selected examples: 1/ the wind-ice effect on a floating photovoltaic structure on the Łapino Reservoir; 2/ the effect of wind on polynya (a type of ice gap) in the Vistula Lagoon.

Arguably, the research conducted by Ms Radan may not be considered a scientific achievement "in and of itself". However, I have no doubt that the results obtained, and the conclusions drawn from this work represent significant scientific contributions. Notably, the following findings (results) are both scientifically intriguing and practically valuable:

- In the PIV and PTV measurements aimed at studying the impact of wind on ice drift, the preferred approach for analysing ice velocity measurements (obtained using PTV) is to utilize not the entire measurement area but a limited region adjacent to the wind velocity measurement field (using PIV). This method ensures that the results are more reliable.
- A mathematical description of ice phenomena in rivers and reservoirs is provided by the two-dimensional coupled numerical model DynaRICE, which is based on a hydro-dynamic model and an ice dynamics model. Based on her research, Ms Radan has positively verified the feasibility of using this DynaRICE programme for the numerical simulation of ice floe or ice cover drift under the influence of wind (especially with the provision of appropriate input data). Moreover, she has shown that, in civil engineering, this DynaRICE model can be used in predicting real-world scenarios of the impact

of wind on ice, especially with regard to the interactions with river channels and hydraulic structures.

- For the Łapino Reservoir, by using field data and the DynaRICE model, Ms Radan demonstrated that very strong winds (blowing from the north at a speed of 10 to 26 m/s) led to the formation of an ice jam around the floating photovoltaic platform. Variable forces (normal and tangential) appeared. By acting on the structure, these forces caused it to tilt.
- At times, within the seasonal ice cover of the Vistula Lagoon, wind-driven formations known as polynyas (a type of ice gap) occur. The Doctoral Candidate has compared the location and size of polynyas simulated using the DynaRICE model with field observations and a very good agreement was achieved. In doing so, she demonstrated the ability of the DynaRICE model to simulate both the lagoon's hydrodynamics and the wind-induced variations in the ice cover.
- Drawing on the conducted tests and the analysis of the wind–ice interaction, Ms Radan's conclusion that wind speeds above 2 m/s play a crucial role in ice dynamics is also of significant importance. Equally important is the suggestion that a proper mathematical description of shear stress imposed on ice by wind ($\tau_{s,a\text{-}i}$) should also incorporate the influence of ice concentration and floe size. Moreover, Ms Radan has identified an inverse linear relationship between ice concentration and mean ice drift speed, with ice velocity decreasing as the concentration increases.
- In numerical modelling of the effect of wind on ice the role of wind drag coefficient (C_a) is fundamental. In the DynaRICE model it is assumed to be constant and usually equals 0.0015. However, the Doctoral Candidate showed that this drag coefficient is not constant throughout the entire range, but varies with wind velocity. Special attention and praise should be given to the results of her research presented in Table 5-1 and illustrated in Figure 5-14. They clearly show that the lower the wind speed, the higher the drag coefficient (0.0020, 0.0025, and 0.0090, respectively). This is a crucial conclusion, which also implies that a wind velocity that is too low will not cause the ice to move because of the frictional resistance. However, at least in my opinion, it is more appropriate to depend this coefficient not only on the speed but rather on the Reynolds number (Re), also taking into account the viscosity and the geometry of the fluid/air flow. Such studies have already been carried out for liquids, but also in aeromechanics (and I strongly encourage further research in this direction).

In conclusion, I affirm that the research results obtained by the Doctoral Candidate undoubtedly represent her original contribution to the scientific discipline. My assessment of the research methodology is entirely positive (despite some discussion points raised below). The results obtained should be considered reliable. They have been correctly processed, presented, and commented upon. It should also be emphasized that Ms Radan's analyses of the research results are strongly supported by statistical processing of the measurement data. Moreover, I believe that the final conclusions of the dissertation laid out in Chapter 8 are fully justified by the results obtained and are related to the objectives set out at the beginning of the work. To sum up: the layout and structure of the thesis, as well as the division of content in its individual sections, are correct, and the scientific and research content of this dissertation does not raise any significant objections, and I assess it positively.

Content-related remarks and points for discussion

During the review of the dissertation, the following comments came to my mind, and I would like to ask the Author to kindly address them during her public defence:

- In my opinion, when analysing the dynamics of ice phenomena without accounting in the tests for the mutual interactions between ice floes (and, for example, the resulting formation of ice jams), and specifically without considering the ice-related thermal processes (including the changes in the size and thickness of ice cover due to melting or freezing), the scope of research as well as the understanding of wind-ice interactions are significantly limited. In her tests (including in the wind field analysis), Ms Radan has decided to make some simplifications and for this reason, I see the need for further research and its continuation on a broader scale, which I strongly encourage.
- In general, in line with the principles applicable in wind engineering, any laboratory research on the impact of wind on various bodies (including ice floes) and structures (e.g., bridges) should be conducted in a special wind tunnel (Flaga, 2008), and in a manner adhering to specific principles and similarity criteria for the phenomenon's course in the model and in nature ("scaling"). This last remark also applies to hydraulic research. In the tests, a substitute was used for both the ice floe (10x10x1 cm) and the ice cover (40x50x1 cm), as well as a water-wind flume with specified dimensions. What geometric scale was adopted for the laboratory model tests, and were the values of the flow velocities obtained for ice and wind appropriately converted? How to explain the issue of the so-called scale effect on the results? How should one treat these results in terms of their implications for nature and engineering practice? Can these research results be considered universal, or are there some limitations in their applicability?
- Given the numerical simulations using "DynaRICE" and the reliability of the results thus obtained, the issue of proper model calibration becomes significant. Please clarify how the problem of calibrating the roughness of the bottom surface of the ice cover was addressed?
- The concentration of ice pieces in the test flume was one of the key variables in the laboratory tests. However, in the dissertation, the procedure for determining the value of this parameter is addressed rather superficially. With regard to the repeatability of the experiment or its continuation in other research centres, please provide more details on how the concentration of ice pieces was determined. Was it the volumetric method? How to understand the concentration value of 0.70 that is given? Does it mean 70%? Or perhaps it is the number of ice pieces per 1 m^2? (in which case the unit is a must).
- In the conducted wind field studies, a very modern, non-invasive measurement technique, PIV (Particle Image Velocimetry) was applied, that requires "seeding" the measurement area with appropriate markers (seeding particles). For this purpose, Ms Radan used water droplets sprayed into the flume from special sprayers. There are reports in the literature, that water is not the best choice for the marker due to the possibility of evaporation or droplet aggregation, which may distort the measurement results. Because of its properties, the "DEHS" aerosol (Di-Ethyl-Hexyl-Sebacate), which is (among other benefits) far more stable, is a much better medium for visualising the wind stream. DEHS is an insoluble, colourless, odourless, non-hygroscopic and easily dispersible liquid with low viscosity, and low evaporation rate (a droplet with a diameter of 0.3 μm has a lifespan of 4 hours!). What is the Doctoral Candidate’s opinion on this issue?
- Without a clearly stated research hypothesis, which is then verified through the achievement of the defined objectives and research tasks (as in the case of a scientific

dissertation in its classical form), the dissertation submitted for review takes rather the form of an extensive and detailed research report. Formulating one or several hypotheses (e.g. "Ice drift dynamics in stationary water bodies depend on wind velocity as well as the ice size and concentration" or "Shear stress imposed on ice by wind depends on wind velocity and ice size and concentration") enriches and organises the research part of the dissertation.

Assessment of the editorial aspect of the dissertation

In terms of editorial quality, only a minor drawback can be pointed out, namely that there is no list of figures and tables. On the other hand, the photographic documentation included in the dissertation is very well chosen and highly helpful in understanding the research area and properly interpreting the descriptions provided in the text. Particularly the photographs in Chapter 3 allow for a step-by-step following of the research process and "participating" in the laboratory experiment. Overall, the editorial aspect of the dissertation is correct. In my opinion, the publication of this dissertation is highly recommended – either as a monograph or even as a series of articles, which I strongly encourage. The findings of Ms. Parisa Radan are a valuable source of specialized information and may serve as a starting point for further research.

SUMMARY AND FINAL CONCLUSIONS

I hereby acknowledge that the research objectives set out by the Doctoral Candidate at the beginning of the dissertation have been achieved through experimental model studies conducted in a hydraulic laboratory, computer simulations (including a real-case study), as well as comprehensive and detailed analyses of obtained data and have also been appropriately discussed in the conclusions of the dissertation (Chapters 7 and 8).

Ms Radan’s dissertation represents an original solution to a scientific problem and demonstrates that the Author holds sufficient theoretical and specialized knowledge in her field, along with the capacity to independently plan and conduct scientific research.

In view of the scientific, cognitive, and applicative merits of the doctoral dissertation entitled "Wind Effect on Ice Dynamics", which I evaluate positively, I hereby request that the High Council of the Scientific Discipline of Civil Engineering, Geodesy, and Transport at Gdańsk University of Technology allow Ms. Parisa Radan to proceed to the public defence and further conduct of the doctoral procedure, as she meets all the requirements for doctoral theses set out in the Act of July 20, 2018, "Law on Higher Education and Science", Journal of Laws of 2023, item 742, as amended; Chapter 2, "Doctoral Degree / Awarding of the Doctoral Degree," Articles 186, paragraph 3a and 187) ("Prawo o szkolnictwie wyższym i nauce", Dz.U. z 2023 r., poz. 742, z późn. zm.; rozdz. 2 "Stopień doktora / Nadawanie stopnia doktora", art. 186, pkt. 3a oraz art. 187).

Prof. Tomasz Tymiński