Australian National University

Anonymous examination report for candidate

Candidate and candidature details

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Academic Career	Research
Academic Program	9060XPHD - PhD Science

Examination report

Thesis entitled: Simulation of rapidly varying and dry bed flow using the Serre equations solved by a finite element method
Candidate: Jordan P.A. Pitt, ANU
Examination Report:
I have now completed my review of this PhD research work and I recommend that the thesis be awarded subject to minor changes being made to the satisfaction of the delegated authority. I thoroughly enjoyed reading this thesis. It is well-written and the chapters flow in a logical sequence.
The development of an experimentally calibrated computational model that can predict complex flow behaviour, the presence of steep gradients, interactions of dispersive waves with varying bathymetry, wave-breaking, and the wetting and drying of a sloping beach is a very challenging research topic. The candidate and his supervisory team should be congratulated on their excellent efforts in advancing the current knowledge in this field. I believe the outcomes of this work could have a significant impact on informing the development of future modelling capabilities in higher spatial dimensions. Furthermore, the work from the thesis has been published in high-impact international journals. The publications make noteworthy contributions to the literature and clearly demonstrate the academic ability of the candidate.
The thesis is presented over seven chapters. In chapter 1, the background and motivation for the research is given and the objectives of the thesis are stated clearly. The motivation of using the Serre equations over the shallow water equations to model water waves is also made clear. The candidate then summarises the original contributions that the thesis research makes to the literature and provides an overview of the four publications that arose from the work. Then, in chapter 2, the literature related to the Serre equations is reviewed. At first the Serre equations are introduced and the one-dimensional model is derived. Next, the Serre equations are written in conservational form with a source term so that the finite volume method can be applied. To conclude this chapter, a range of analytic solutions are presented that are used to assess the accuracy and performance of the proposed numerical methods. The forced Serre equations and the concept of forced

solutions are also provided.
In chapter 3, the full details of the second-order finite element method (FEVM) are given. The full description of the linear analysis for FEVM is provided in chapter 4, where the convergence and dispersion properties are investigated. Similar results are deduced for the five other methods considered. I found this chapter very informative and clearly presented.
In chapter 5, the analytic and forced solutions are used to validate the numerical methods presented throughout the previous chapters to ensure the solutions behave in a consistent and conservative manner. Convergence measures are introduced to assess the numerical schemes. The defined measures are used at first to compare the numerical methods for the solitary travelling wave solution, and then the convergence and conservative properties are compared for the lake at rest solution. The presentation of the results is well done. I felt the analysis is rigorous, correct and presented in a consistent manner. The results were also convincing and were as expected for these types of schemes. They also highlight the need for high-order accuracy in the numerical approximations. The conclusion that second order accuracy is sufficient is certainly something I've found in the past as well.
In chapter 6, the second-order FDVM and second-order FEVM schemes are validated using experimental data. This data is used to assess the capability of each method for simulating different physical scenarios. The results are impressive, with both methods recovering the main distinguishing features of the experimental data. These findings demonstrate the accuracy of the numerical methods in the presence of steep gradients in the free surface. For the periodic waves case study, the simulations show the importance of the dispersion terms in the Serre equations as being crucial for capturing the experimental observation.
In chapter 7, the main results and outcomes of the research are summarised and the potential future directions of the work are given.
One suggestion for improving chapter 7 would be to give further insight on the challenges that might be faced in extending the mathematical and computational foundations presented throughout the thesis to higher dimensions. An immediate question that arises when implementing the schemes on unstructured grids is how the flux limiter might be implemented and also how the interpolation schemes would be extended to higher dimensions, and the impact this would have on the solver and overall computation time.
I now provide further feedback for the candidate to consider when preparing the final version of the thesis for submission to the university.
As a general comment, please check the style of using "I" and "we" throughout and consider writing in the third person.
Chapter 1: is well written. Perhaps the literature related to the numerical solution of these types of conservative equations could be broaden. For example, what numerical methods/strategies have been employed previously for the shallow water equations?
Chapter 3: should include further discussion on use of flux limiting methods for these types of conservative models. At the bottom of pp. 25, explain meaning of "robust". The treatment of boundary cells and general boundary conditions should be expanded. On pp 28, remind the reader of what h, w, b, and G are. The introduction of SSP is brief and could be expanded (as well as alerting the reader that further details will be provided later in this chapter). Sometimes notation is not always clear,

for example on pp 29 what is $q_{-1/2}^{+}$, etc? On pp 30, explain why this particular reconstruction method was used. There are many other limiters published in the literature and I recommend giving further background. On pp 32, I think it would helpful to provide some details of the spaces introduced and then refer to Appendix B for further details. In equation (3.7) typo ",". On pp 37, elaborate on the conditioning of the matrix and discuss whether pivoting strategies are required (this becomes more apparent on pp 45). Was any structure of the matrix considered? On pp 40-41, I thought the section on source terms could be improved by adding more detail. It wasn't made clear to the reader why this strategy was necessary. On pp 42, more discussion of the temporal scheme should be provided. Why was this particular scheme chosen and what is a typical value of time step that can achieved during the simulations for the solver? On pp 44, I think this type of transformation (3.25) may have been employed for solving Richard's equation in groundwater modelling scenarios, it would be useful to broaden the literature on this to provide the reader with further insight.

Chapter 4: Please check the use of "elementwise" throughout. It should be one word. On pp 63, there is some confusion with λ used in different contexts on that page.

Chapter 5: The comments around the third-order SSP RK method seem to suggest something else may have caused the issues experienced. I felt further investigation on this might be warranted. The family of exponential integrators might be worth consideration in the future. This chapter may also have provided a good opportunity to make computation time comparisons between the different methods and highlight any trends in the time step history (adaptation) of the methods considered.

Chapter 6: Possibly consider another read of this chapter as some smoothing of the English presentation is still required. For example, on pp 97, the sentence starting "While all the conserved quantities…" could be reworded. Same for the sentence "Where a higher resolution…" seems incomplete. On page 116, the sentence "Where the technique…" could also be reworded.

Chapter 7: In its current form his chapter is too brief. In the first paragraph the candidate states the work resulted in "new behaviours and the resolution of differences" (in what exactly?). These are important statements (and contributions) that should be further elaborated. I felt that the major contributions summarized on pp 130 could be linked to the research questions and original research objectives stated in chapter 1. Each bullet point could be expanded to refer to a specific outcome achieved in an earlier chapter. More details on future work could also be provided.

In closing, I would like to take this opportunity to wish the candidate well for their future academic endeavours.