# FLOW VISUALIZATION ON DOWNSTREAM OF RECTANGULAR SHARP-CRESTED WEIR WITH FREE FALL FLOW

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A thesis submitted in fulfillment of the requirement for the award of the Doctor of Philosophy of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering Universiti Tun Hussein Onn Malaysia

SEPTEMBER 2023

#### **DEDICATION**

#### To my beloved mother and father,

Pn. Salama Manap & Allahyarham Malik Fesal Bin Suaib For being the backbone of my life by supporting me from the very beginning

### To my supervisor and mentors,

Prof. Dr. Mas Fawzi Bin Mohd Ali Dr. Rais Hanizam Bin Madon Assoc. Prof. Ts. Dr. Mohd Azahari Bin Razali Assoc. Prof. Dr. Mohammad Kamil Bin Abdullah Tc. Mzahar Bin Abd. Jalal For their consistent encouragement, guidance, and support throughout the

research journey

### To my siblings, family and friends

Close family members & true friends For their trust, cooperation, and motivation during this project

### To supporting organisation

Ministry of Higher Education (MOHE) Polytechnic and Community College Education Department (DPCCE/JPPKK) Maritime Technology Academy @ Politeknik Bagan Datuk Mechanical Engineering Department @ Politeknik Ungku Omar For their direct and indirect support in completing various stages of this research

#### ACKNOWLEDGEMENT

# بِسْمِ اللهِ الرَّحْمٰنِ الرَّحِيْمِ

First and foremost, all praises and thanks to Allah SWT, the Almighty, for His showers of blessings throughout my research work to complete the research successfully.

I would like to express deep and sincere gratitude to everyone involved in completing this project, especially to my research supervisor, Prof. Dr. Mas Fawzi bin Mohd Ali for his guidance and counseling throughout my Doctoral project's success. I would also like to thank my committee members for letting my defense be an enjoyable moment, and for the brilliant comments and suggestions, thank you.

Shall to d prov wou Mul bin

Dr. Rais Hanizam bin Madon, Mr. Mzahar bin Abd. Jalal and Assoc Prof Dr. Shahrul Azmir bin Osman for providing guidance in helping me set up the equipment to do the experiment. Special thanks to Universiti Tun Hussein Onn Malaysia in providing facilities such as laboratories, equipment and library for reference access. I would like to thank my colleagues Dr. Mustaqim bin Tukiman, Dr. Muammar Mukhsin bin Ismail, Mr. Putera Mohd Adam bin Amat Azman, Mr. Anwar Syahmi bin Adlin Zafrulan and all Autopreneur Laboratory members, who have given me support and help during my study at Universiti Tun Hussein Onn Malaysia.

Not forgotten, to members of my family, especially my late beloved father, Malik Fesal bin Suaib, my mother Salama Manap for their continuous support and prayer that never stop for me in completing this doctoral project. The pillar of my strength goes to both my daughters; Camalia Anggun Raihanah and Balqis Intan Baizurah for their warmest company and lastly the love of my live who keeps motivating and inspiring me throughout the journey. From the bottom of my heart, thank you.

### ABSTRACT

The characteristic of counter-current phenomenon on downstream channel for sharp crested weirs, and vertical drop hydraulic structures has been a challenge in fluid dynamics for many years. This study focuses on the interaction between two distinct flow regimes, namely free fall, and modular transition flow, in an open channel. The experiments were conducted with several upstream conditions of head over weir crest,  $h_c/P$  for 0.3, 0.4, 0.5 and 0.6 with tailwater depth of  $h_t$  of 0.7 P, 0.8 P and 1.0 P, with P is the height of the sharp-crested weir. The experiments were performed in twodimensional (2D) plane the flow visualization method with Froude number, Fr ranging from 1.0 to 5.4. The flow characteristics were analyzed, including velocity distributions, hydraulic Froude number, Fr, and excitation frequency from downstream of rectangular sharp-crested weirs. The study revealed the occurrence of two types of Von Karman vortex streets; regular and reverse, in the vicinity of the downstream channel, with significant vortex frequency shedding based on each tailwater depth. The excitation frequency, fst range, was discovered to vary with tailwater depth. The maximum value for excitation frequency, fst, with a tailwater depth of  $h_t = 0.7$  P, 0.8 P and 1.0 P, were 40 Hz, 50 Hz, and 85 Hz respectively, while the minimum excitation frequency, *fst*, for all cases was zero. The excitation frequency played a significant role in the oscillatory period within the counter-current region until it diminished into the recovery zone. Overall, our research extends the knowledge of nappe flow in open channels by providing new insights into the velocity distribution and the relationship between vortices and the frequency of Strouhal. This information can be used to optimize the design and operation of open channel systems, improving their safety, sustainability, and efficiency.



### ABSTRAK

Kajian ini memberi tumpuan kepada fenomena arus bertentangan di saluran hiliran bagi empang dasar segiempat tepat berpuncak tajam dan struktur hidraulik turun tegak. Interaksi antara dua rezim aliran berbeza, iaitu jatuh bebas dan aliran modular transit, telah dikaji dalam saluran terbuka. Eksperimen dijalankan dengan ketinggian di atas empang berpuncak tajam terhadap tinggi empang berpuncak tajam,  $h_0/P$ , pada 0.3, 0.4, 0.5 dan 0.6 dengan kedalaman air ekor,  $h_t = 0.7$  P, 0.8 P dan 1.0 P, di mana P adalah ketinggian empang berpuncak tajam. Eksperimen dilakukan dalam dua dimensi dengan menggunakan kaedah visualisasi aliran dengan julat nombor Froude dari 1.0 hingga 5.2. Ciri-ciri aliran dianalisis termasuk taburan halaju, taburan nombor Froude hidraulik, dan frekuensi rangsangan daripada hiliran empang tajam segiempat. Kajian ini mendedahkan dua jenis pusaran Von Karman, iaitu teratur dan putar balik, di sekitar saluran hiliran dengan rangsangan frekuensi pusaran yang ketara berdasarkan kedalaman air ekor. Frekuensi rangsangan, *fst*, didapati berbeza dengan kedalaman air ekor. Nilai maksimum untuk frekuensi rangsangan, fst, dengan kedalaman air ekor  $h_t$ = 0.7 P, 0.8 P dan 1.0 P adalah 40 Hz, 50 Hz, dan 85 Hz, masing-masing, manakala frekuensi rangsangan minimum untuk semua kes adalah sifar. Frekuensi rangsangan memainkan peranan penting dalam tempoh berayun dalam kawasan kontra-arus sehingga ia berkurangan ke dalam zon pemulihan. Secara keseluruhannya, kajian ini memperluaskan pengetahuan tentang aliran nappe dalam saluran terbuka melalui pengedaran kelajuan dan hubungan antara vortices dan frekuensi Strouhal. Kajian ini boleh digunakan untuk mengoptimumkan reka bentuk dan operasi sistem saluran terbuka, meningkatkan keselamatan, kesinambungan dan kecekapan mereka.



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### 5.2 Future Works

A novel method for the estimation of the velocity distribution in smooth open channel flows has been developed. The hydrodynamic interaction between the free surface flow and the hydraulic structure affected the Reynolds shear stress distribution and the turbulent intensity. As a result, coherent structure formation was seen on streamwise channel. The following are potential future works which are highly recommended for open channel experimentation such as on river engineering application:

- i. Further study on bedforms evolution using submerged particle substance would be recommended since the particle velocity can affect the production of rough surface.
- ii. Investigation of velocity distribution in open channel can be improved by considering the shear stress distribution and time average during experimentation in open channel.
- iii. Secondary flow investigation on velocity distribution will be beneficial to improve the velocity distribution analysis and is recommended for Three-Dimensional analysis (3D).
- iv. The study of velocity distribution will also be very beneficial to improve the sedimentation analysis.
- v. Exploring the use of frequency excitation to control the formation and behaviour of vortex rings in tail water conditions, and its potential applications in fluid mixing or flow control.
- vi. Investigating the impact of tail water on the performance of flow energy harvesting devices using vortex frequency excitation, and how the effectiveness of these devices can be optimized under different tail water conditions.
- vii. Developing new numerical simulation methods to model the effect of tail water on vortex shedding and frequency excitation and validating these simulations with experimental data.
- viii. Investigating the effectiveness of frequency excitation methods in mitigating the tail water effect on vortex shedding and flow-induced forces.

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