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

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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

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For their consistent encouragement, guidance, and support throughout the research journey

To my siblings, family and friends

Close family members & true friends

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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 two-dimensional (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_c/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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i. Fesal, S. N. M., Fawzi, M., & Rizan, M. (2019). Low Head Dams Awareness in Malaysia. TEST Engineering & Management.

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VITA

Siti Natasha Malik Fesal was born on July 24th, 1981, in the Federal Territory of Kuala Lumpur. Her early schooling was in Wangsa Maju before her family relocated to Ipoh, Perak when she was a decade old. She completed her primary education at Sekolah Kebangsaan Sg.Rapat in Ipoh. For her secondary education, she attended the distinguished SMK Gunung Rapat in Ipoh, followed by MRSM Balik Pulau. In 2004, the author was graduated with a bachelor's degree in mechanical engineering from the College Universiti Tun Hussein Onn Malaysia (KUiTTHO) situated in Batu Pahat, Johor. She continued her academic journey at the same institution, now recognized as Universiti Tun Hussein Onn Malaysia (UTHM), and earned her master's degree in mechanical and manufacturing Engineering in 2015. Concurrently, she embarked on her doctoral studies in Mechanical Engineering under the guidance of the Faculty of Mechanical and Manufacturing Engineering (FKMP) at UTHM. With a passion for education, Siti Natasha has been an integral part of the faculty at Politeknik Ungku Omar for the past nine years. Specializing in subjects like Fluid Mechanics and Autocad, she has actively engaged in research endeavors centered on fluid flow dynamics (specifically CFD), material mechanics, and energy management and efficiency. Recently, she transitioned to the Maritime Technology Academy at Politeknik Bagan Datuk, where she imparts knowledge on Engineering Drawing, Autocad, and Mechanics of Dynamics. Her professional achievements also include being a Registered Graduate Engineer and a Certified Autodesk Instructor.