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It is certified that the work contained in the thesis titled **"EXPERIMENTAL AND NUMERICAL STUDY OF FLOW AROUND PIANO KEY WEIR"** by **MR. AMIYA ABHASH** has been carried out under my supervision, and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive, Candidacy and SOTA.

Signature: Supervisor

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Department. of Civil Engineering
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DECLARATION BY THE CANDIDATE

I**, Amiya Abhash,** certify that the work embodied in this thesis is my own bonafide work carried out by me under the supervision of **Dr. Kamlesh Kumar Pandey** from **July 2016 to July 2021** at the **Department of Civil Engineering, Indian Institute of Technology (BHU) Varanasi.** The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully lifted any other's work, paragraphs, text, data, results*, etc.,* reported in journals, books, magazines, reports dissertations, thesis, *etc*., or available at websites and included them in this thesis and cited as my own work.

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Supervisor
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…Dedicated To My Family

Present and Expecting…

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AMIYA ABHASH

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ABBREVIATIONS AND SYMBOLS USED

B	:	Upstream-Downstream lateral crest length of PKW
B_b		Base length
BCs		Boundary Conditions.
B_i	:	Downstream (inlet key) overhang crest length
B_i/ B_o	:	Length of downstream/upstream cantilever overhang
B_o	:	Upstream (outlet key) overhang crest length
C	:	Numerical coefficient for head discharge relationship
C_d	:	Coefficient of Discharge under free-flow condition
C_s	:	Coefficient of discharge under submerged flow condition
d	:	Sand grain diameter (mm)
g	:	acceleration of gravity (m^2/s)
H	:	Water head at sufficient distance upstream of PKW (upstream flow depth measured relative to the weir crest) (m)
h	:	average water head at middle of the lateral crest of PKW (m)
L	:	Total developed length along the overflowing crest axis (m)
P	:	Vertical height of PKW (m)
Pi	:	Height of inlet of PKW(m)
PKW	:	Piano Key Weir
Q	:	Discharge (L/s)
R^2	:	Coefficient of determination
Re	:	Reynolds number
Relative ratio	:	Increased discharge ratio (Q_{PKW}/Q_W)

(r)

RMSE	:	Root Mean Square Error
RPKW	:	Piano Key Weir with a rectangular plan
TPKW6, TPKW9 and TPKW13	:	Piano Key Weir with a trapezoidal plan and α = 6, 9 & 13 degrees
T_s	:	Sidewall thickness
u	:	Stream wise Velocity
V	:	Velocity (m/s)
v	:	Velocity Component of Velocity(V) along vertical direction (Y) (m/s)
W	:	Width of channel (m)
W_e	:	Weber number
W_i	:	Inlet key width (sidewall to sidewall)
W_i/W_o	:	Inlet/Outlet Key width ratio
W_o	:	Outlet key width (sidewall to sidewall)
X	:	Axis for Stream wise Direction (m)
Y	:	Axis for Transverse Direction (m)
y	:	Instantaneous depth from bed (In vertical plane)
Z	:	Coordinate along transverse direction (m)
Z	:	Axis for Vertical Direction
z	:	Relative Depth
α	:	Angle between the lateral crest and the longitudinal direction in the direction of flow (degrees)
ρ	:	Density of Water

ABSTRACT

A systematic approach has been undertaken in the present study comprising an experimental and numerical study of flow around Piano Key Weir. Piano Key Weir is a new, improved form of labyrinth weirs, and a review of Piano Key Weir (PKW) has been presented in the Literature Survey. The review study compares PKW in its hydraulic superiority to its counterparts. It focuses on many critical factors like economy, aeration requirements, structural integrity, different plans of PKW, sediment carrying capacity and self-cleaning ability.

The preliminary step of the present study investigates the hydraulic advantage of Piano Key Weir compared to the rectangular weir in an open channel. The present study then investigates the use and validation of Computational Fluid Dynamics (CFD) for modeling Open Channel flows over complex hydraulic structures such as PKW. Small discharges with the entire range of head to height ratio h/P from 0.035 to 0.1 have been studied where 'h' is not the total head upstream of PKW but the head measured at the crest of PKW. The numerical results have been validated with experimental results from the literature. Since the discharge is minimal, surface tension force has been incorporated in the numerical model. The numerical model is a half PKW unit model with the same geometrical parameters as the experimental setup and compares the head obtained from CFD studies on the ANSYS platform with that of the literature. Investigation of water surface profile and velocity profile near the upstream portion of PKW has also been carried out. The results show that CFD simulations can reproduce flow depths near PKW with reasonably good accuracy.

Focussing on shape optimization, it is imperative to study the performance of different shapes of PKW to know which shape offers more hydraulically and cost-effective

advantages over other shapes. Much research has been done on rectangular plan-form, while other plan-forms warrants attention. Extensive laboratory investigations have been carried out to study the head-discharge relationship of Piano Key Weirs (PKWs) of different plan shapes for the same no. of repeating cycles of PKW unit and same upstream-downstream crest length in open channel flow of fixed channel width.

The first flume of smaller width (40 cm) has been utilized for head reduction study and the sediment carrying capacity upstream of PKW. The study combines the experimental and numerical study of discharge capacity and sediment carrying capacity of the different plan geometries of PKW. The experimental study of the discharging capacity of PKW has been carried out at eighteen discharge points for three plan geometries of PKW. A numerical study using ANSYS FLUENT has also been carried out at five discharges and compared with the experimental results.

Velocity distribution around hydraulic structures such as Piano Key Weir can be essential for efficiency improvement and local mechanism development. Sediment profile in the channel has been studied at three discharges experimentally for two types of PKWs: RPKW and TPKW6, all for free-flow conditions. An investigation of the vertical velocity profile upstream of PKW has been studied with the numerical model. Critical areas have been identified upstream of PKW where the vertical velocity component ('v') is highest. This distribution around Piano Key Weir is substantive in understanding local transport mechanisms helping the sediments pass over the weir. The study examines the head discharge relationship, velocity distribution and sediment profiles in the approach flow domain of Piano Key Weir of different plan shapes.

The study shows PKW with a rectangular plan (RPKW) to be more hydraulically efficient than TPKWs with six-degree and thirteen-degree lateral crest variations

(TPKW6 & TPKW13). The range of mean longitudinal velocity has happened to be increasing as moved away from the Piano Key Weir. Velocity distribution in the YZ plane is highly nonlinear. The study also shows RPKW to be more self-cleaning in nature than its trapezoidal counterpart (TPKW6). Numerical study shows a close resemblance to the experimental results with errors well within permissible limits implying its greater use in ascertaining complex flows around hydraulic structures.

The second flume, which is 0.984 m wide, has been utilized again to study the head discharge relationship and the effect of outlet submergence in the discharging capacity of PKWs with rectangular (RPKW) and trapezoidal plan (TPKW). RPKW and TPKW 9 have been studied with this second flume. A total of ten to thirteen experimental discharges were tested on each plan geometry. A numerical study using ANSYS-FLUENT has also been carried out for all the plan geometries for both flumes and validated by experimental results. The tailgate was closed to render the PKW's outlet from partial to fully submerged conditions. The effect of these submerged outlets was studied for any changes in the head over the crest of PKW. The study finds that under partial to complete submergence of PKW outlets, both PKW units' discharging capability remains unchanged.

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