SIMULATION OF FLOW CHARACTERISTICS OVER A BROAD CRESTED WEIR USING HEC-RAS SOFTWARE

A Dissertation

Submitted in partial fulfillment of the requirements

for the award of the degree of

Master of Technology

in

Hydraulics and Water Resource Engineering

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I, **Avneesh Singh Sisodia**, Roll No. **2K20/HFE/01**, pursuing Masters in Tech. (Hydraulics and Water Resources Engg.), hereby declare that the Project Dissertation titled "**Simulation of Flow Characteristics Over A Broad Crested Weir Using HEC-RAS Software**" has been submitted by me to the Deptt. of Civil Engg, Delhi Technological University in the partial fulfillment of the requirements for the award of the degree of Masters of Tech. The content of this thesis is original and has not been derived or copied from any source without giving proper citation. This work has not previously served as the basis for the award of any Degree, Fellowship, Diploma or any other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Simulation of Flow Characteristics Over A Broad Crested Weir Using HEC-RAS Software**" which is submitted by **Avneesh Singh Sisodia**, Roll No. **2K20/HFE/01**, to the Deptt. of Civil Engg., Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Tech. (Hydraulics and Water Resource Engg.), is a record of the project thesis work carried out by him under my supervision. To the best of my knowledge, this work has not been submitted, in part or full, for any Degree or Diploma to this DTU or elsewhere.

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ABSTRACT

Broad-crested weirs serve as an effective device for flow control and measurement, having a less complex geometry and offering an ease of operation and maintenance. Unlike larger and elaborate hydraulic structures like dams and spillways, crested weirs allow the hydraulic engineers to gain appreciable control on regulating the water level in rivers and streams. Having a relatively simpler and more predictable head-discharge relationship, broad-crested weirs can be calibrated easily using modern computational softwares like HEC-RAS and ANSYS Fluent that carry out numerical simulation to predict the flow characteristics of the weir.

Here in this study, experiments were performed on two shapes, one having vertical faces and other with sloped faces. A 4.0 m long, 30.0 cm wide and 50.0 cm deep rectangular tilting flume with an adjustable channel was used to carry out 24 discharge runs in two configurations: horizontal channel bed and at a slope of 2%. Using the basic parameters from the experimental data as input values, numerical simulations were carried out on HEC-RAS and ANSYS Fluent software programs. The data obtained from both the computational approaches were used to validate the experimental results. While HEC-RAS offered an ease of data input and lesser computation time, ANSYS Fluent gave more consistently accurate values of water surface elevations and discharge relative to the experimental data.

ACKNOWLEDGEMENT

I would like to express gratitude to the Vice Chancellor of Delhi Technological University, Prof. Jai Prakash Saini and Prof. V.K. Minocha (Head of Civil Engineering Deptt, DTU). I feel indebted towards my mentor and thesis supervisor Dr. Munendra Kumar, for his constant guidance and motivation throughout the duration of my thesis.

I am also thankful to Mr. Vijay Kaushik, Mr. Deepak Singh, and the technical staff of the hydraulics laboratory at DTU, for their help and support in the completion of my thesis. I am especially grateful to my family who have always aided me at every step to become better.

Place: Delhi

Date: 31.05.2022

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CHAPTER 1
Introduction

1.1 Weirs: A Brief Overview

Owing to the persistent requirement for water for various activities like manufacturing, irrigation, domestic consumption and so on, numerous efforts are undertaken world-wide towards an efficient water management. Weirs are common devices utilized for water-management, and are used to modify the flow of water within streams, canals and rivers. Basically, a weir is a small hydraulic structure, like a small dam, which is constructed across the width of a stream or a river in order to control & modify the water level on the upstream end. It changes the characteristics of water flow and generally results in a height change in the water level in the water body. As hydraulic structures, weirs have long been used for the purpose of controlling water flow in water bodies. The size of weirs can vary both in vertical and horizontal direction. The smallest weirs can be just a few inches in their height, while the largest can go up to several meters tall & hundreds of meters long.

As opposed to larger hydraulic structures like dams, which require reservoirs to be created, the aim of a weir across a water body is not to make available storage, rather to exercise some control over the level of water. A commonly known fact that helps distinguish weirs from dams is that the water usually flows over the weir crest for an appreciable magnitude of length. There could be numerous possible designs in case of weirs, however, generally water passes freely over the weir crest, prior to falling to a lower height.

1.2 Parts of a Typical Weir

A typical weir consists of the following components:

- **Body wall of weir**

  The body wall is to raise the water level on the upstream. It is required to be strong enough to resist water pressure as well as uplift pressure

- **D/S apron**

  It is used for the purpose of reducing the kinetic energy of water. Its length depends upon the nature of soil discharge in the river and the height of fall of water. It is usually extended till the point where no scope for erosion is anticipated. It is expected to have adequate thickness in order to resist the uplift pressure.

- **U/S apron**

  It safeguards the weir from erosive forces at the time of surging floods or heavy rainfall. The linear dimension of the u/s apron relies upon the weir length & river flow-rate. It needs to have sufficient strength to withstand downward pressure of water and to prevent any kind of leakage in subsoil.

- **U/S curtain wall**

  It is used for reducing the uplift pressure, to reduce the exit gradient, and to increase the length of creep. The u/s curtain wall length relies on the properties of subsoil.

- **D/S curtain wall**

  It is used to protect the downstream water flow against uplift pressure. It is required to be strong enough to resist the kinetic energy of water.

- **Crest**

  It is the top of the weir. It has to be strong in order to withstand excessive pressure frequently during the occurrence of floods.

1.3 Flow Measurement through a Weir

Weirs offer a simple method to measure discharge, i.e. the volumetric rate of water flow in small or medium-sized water bodies like rivers and streams, or in industrial sites having large discharge. Since the crest geometry is known in the case of the weir, and all the incumbent flow of water occurs over the weir, it is possible to convert the water-depth behind to a rate of flow. Notably, this is only possible at sites where the water doesn't flow around the sides or through conduits or sluices, rather all of it flows over crest top and is transported away from the structure.

A general equation for calculation of discharge in the case of weir is given as:

$$\mathbf{Q = C.L.H^{n}}$$

Where

- Q: discharge
- C : weir coeff.
- L: crest width
- H: water head over the crest
- n: constant value varying with weir type

1.4 Types of Weirs

Weirs can vary from a simple structure made from stone or masonry to very large & elaborate structures needing large scale management & maintenance. They are usually classified on the following basis:

1.4.1 Shape of weir opening

On the basis of the shape of weir opening, weirs are classified as:

- Rectangular Weir
  This is the standard weir shape. The top edge of the weir can either be narrow-crested or sharp-crested. Rectangular shaped weirs are usually suitable for larger channels. They are often utilized for water supply, wastewater & sewerage systems.

- Trapezoidal Weir

  Also regarded as the Cippoletti Weir, the weir is a modification over a rect. weir having a larger capacity while having the similar strength of the crest.

- Triangular Weir

  It is shaped like a V or a reverse triangle. Therefore, it is often referred to as the V-notch weir. These types of weirs are quite useful to ascertain flow rate over smaller flows and that too at a better accuracy.

1.4.2 Shape of the weir crest

On the basis of weir crest's shape, it is classified as:

- Weir with a Sharp Crest

  It has a flat plate which has, at the crest, a sharp edge. It is fitted into the stream or river in a way that the water flows over the crest so as to fall into the pool downstream of the weir. The flow over a sharp-crested weir is similar to that of its rectangular counterpart. Weir crest is sharpened so that the fluid falls fairly away from the crest. Weir-plate is also beveled at the crest-edges in order to attain sufficient thickness. It needs to be made from smooth metal that is free from rust & nicks.

- Narrow-crested Weir

  If the weir-crest's breadth is less than 0.5 times the height of water above it, then it is generally regarded as a narrow crested weir. It has many similarities to the rectangular shaped weir, having a narrow shaped crest. The discharge is also similar to that over a rectangular weir.

- Ogee-shaped Weir

  This weir's crest climbs slightly, and then into parabolic shape, it falls. Flow is again similar to a rectangular weir. The water spills over the ogee crest and falls in the form of a rolling sheet. Usually, these types of weirs are constructed for the spillway of a dam.

- Broad-crested Weir

  A broad-crested weir consists of an overflow crest that is raised. Although, numerous other shapes of crest can be provided to establish control over the water flow in boundaries horizontal to flow direction. These weirs often offer special approach transitions ahead of and up to the surface of the crest.

  A common example is nose treatments like rounded corners & ramps. The length of the crest in the flow direction is usually sufficient, in comparison to the u/s head, so as to render the flow curvature's influence as insignificant. They are able to adequately avoid friction from the control depths.

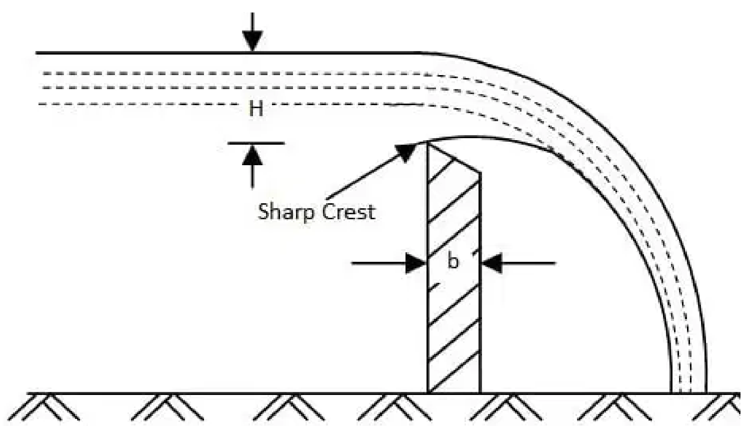


Fig 1.1 Diagram of Sharp-Crested Weir

Source: constructor.org

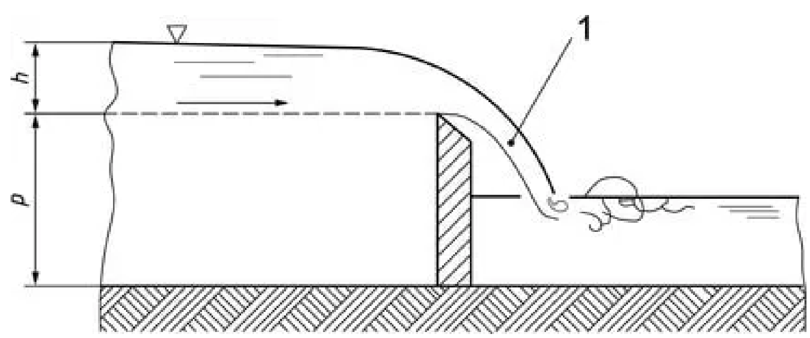


Fig 1.2 Diagram of Narrow-Crested Weir

Source: constructor.org

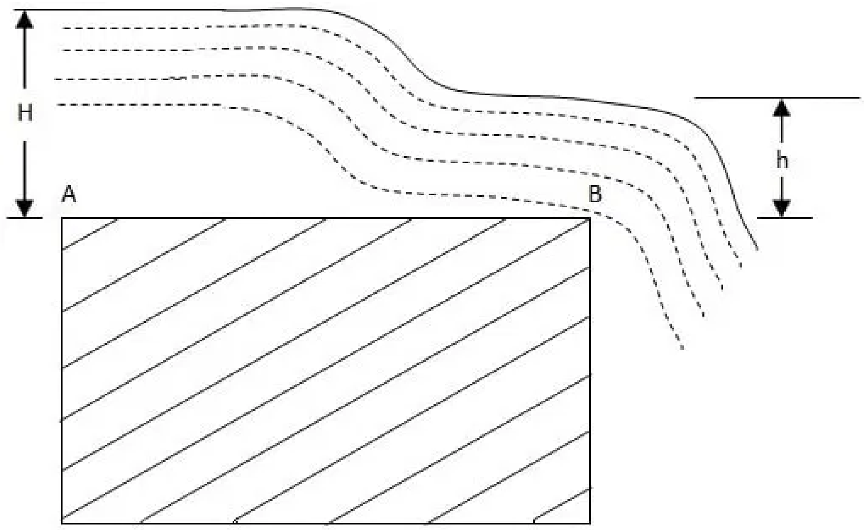


Fig 1.3 Diagram of Rectangular Broad-crested Weir

Source: constructor.org

1.4.3 End contractions:

- Contracted Weir

  The crest of a contracted weir is cut in shape of a notch , similar to a rectangular shaped weir. This type of weir encounters a loss of head. The weir's sides and crest are distant from the sides & bottom of the approach channel. The nappe is contracted fully and laterally at the ends, and vertically at the weir crest.

- Suppressed Weir

  It is a rectangular shaped weir which has its notch coincident with the approach channel's sides, which go on unchanged downstream from the weir. In order to minimize the head loss, the crest of a suppressed weir runs all the across to the channel. The lateral flow contraction is suppressed in this type of weir, hence the name.

1.5 Broad-Crested Weirs

The broad-crested weirs are hydraulic structures utilized for regulating depth, and for the measurement of flow in field as well as laboratory canals. The basic geometry of broad-crested weirs may be described as a hydraulic structure that is flat-crested, having a length that is usually large, relative to the flow thickness over the weir crest.

The weir is termed as broad-crested when the streamlines are observed as running parallel with the crest for a short distance, and it has a hydrostatic distribution of pressure at the control section. The flow over these weirs is termed as modular if it is independent of the variations at the tailwater level.

1.5.1 Basic Functions

- In hydrology, broad-crested weirs are utilized for the measurement of discharge from catchments.
- In irrigation, they are used to ascertain and control the water distribution at bifurcations of canals and also at the off-take structures.
- In sewage and sanitary engineering, they are employed in the measurement of flow arriving into the drainage system, from urban regions and industrial sites.
- In irrigation & drainage, they are capable of regulating the upstream water flow at a desired level.

1.5.2 Noteworthy Advantages of Broad-Crested Weirs

Using broad-crested weirs is often recommended for flow measurement in the open channels, whenever the surface of the water can remain free. According to Bos, Replogle and Clemmens (1984), keeping hydraulic & other boundary conditions similar, broad-crested weirs are usually the most economical of all structures for the accurate measurement of flow. This is due to the fact that they exhibit the following merits relative to any other known weir:

- They can be calibrated with a far greater ease using computational softwares.

- In case any issues like impact, rusting , abrasion, etc. are observed to cause problems in maintenance of a flat-plate weir, a broad-crested weir could be deemed as suitable.
- The head loss over the broad-crested weir necessary to have modularity, is minimal.
- Specially shaped weirs can be curated in order to fit cross sections of complicated channels in a better way. Also the control section's shape might be adjusted for special flow-rate ranging & variation requirements w.r.t. head.
- Some forms of broad-crested weirs, especially those having a round nose, are able to pass sediment and debris in a much better way than sharp thin-plate weirs.

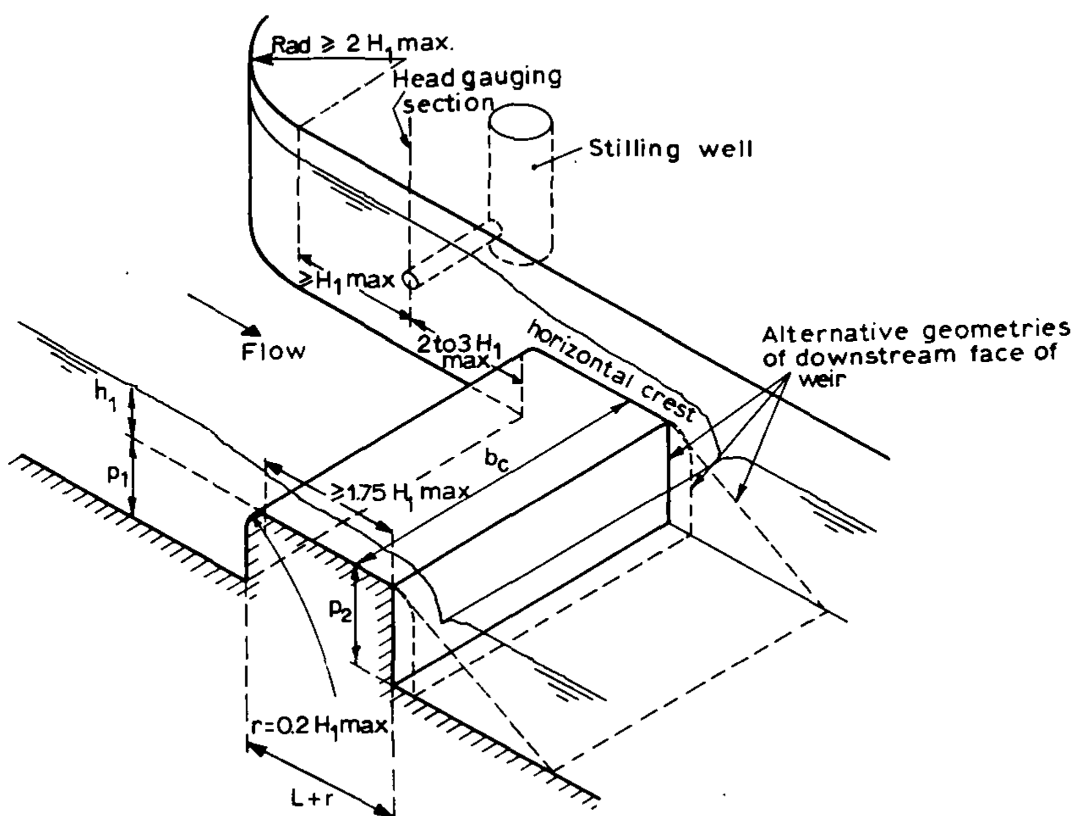


Fig 1.4 Dimensions of round-nose broad-crested weir and its abutments

Source: BSI 1969

1.5.3 Derivation of Discharge formula for Rectangular Broad Crested Weir

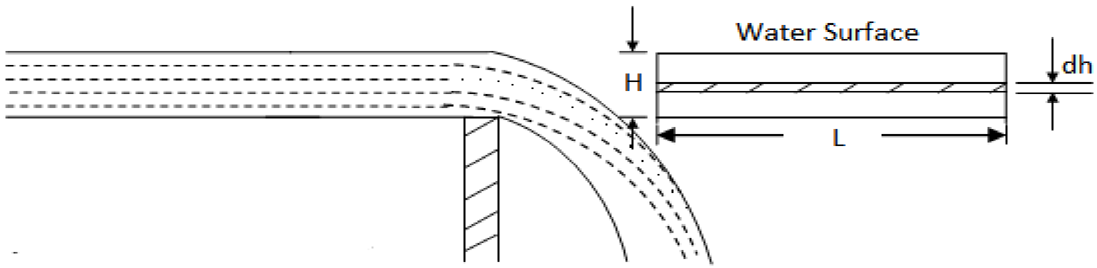


Fig 1.5 Rectangular Weir

Source: www.codecogs.com

Assumptions: Height of water above the weir crest (H), Weir Length (L), and Discharge Coeff. (C_d)

For a horizontal strip of a thickness dh at depth h from the surface,

Area = $L.dh$

Theo. velocity of water through the strip = $\sqrt{(2gh)}$

Thus, if dq is discharge through water strip,

$\therefore dq = C_d.L.dh\sqrt{2gh}$

Total discharge (Q) over the weir is given by:

$$Q = \int_0^H C_d.L.dh\sqrt{2gh} \Rightarrow Q = C_d.L\sqrt{2g}\int_0^H h^{\frac{1}{2}}.dh$$

$$\therefore Q = \frac{2}{3}C_d.L\sqrt{2g}(H)^{\frac{3}{2}}$$

The above equation can be regarded as the formula for calculation of discharge over a rectangular broad crested weir.

1.6 Significance of Numerical Modeling and Simulation of Flow

Most processes in natural as well as engineered systems involve flow & transport processes which take place across a very wide range of physical applications. In fact, the progress in understanding flow & transport along with their interaction with other physical processes is strongly dependent on the accuracy, adequacy, and efficiency of numerical modeling & simulation.

1.6.1 Criteria to evaluate the need for simulation

To recognize whether simulation is the right approach for the solution of a particular problem, four things can be evaluated beforehand:

- **Type of Problem**

  If there is an analytical manner of tackling a problem, simulation is redundant. Sometimes algorithms or mathematical equations prove to be quicker and cheaper than simulation. Also, if the problem gets resolved via experiments directly performed on the system, then doing so is certainly desirable as opposed to carrying out the simulation process.

- **Resource Availability**

  Manpower & Time are significant for carrying out any study involving simulation. Having experience in analysis proves to be very useful, as this helps determine both the appropriate level of detail in the model, and how to verify & validate it. It helps avoid development of a wrong model and its consequent unreliable results. Additionally, the time allocation should not be so limited that it forces one to look for faster but less reliable methods in the process of design. The schedule must allow sufficient time for the implementation of any important alterations, and for validation to get decent results.

- **Cost**

  It is an important factor to consider in the simulation process. Purchasing the software of simulation software, acquiring the computing resources are involved.

Simulation should be pursued only if these costs don’t surpass the potential savings in modifying the current system.

- **Data Availability**

  Data should be sourced properly, and if unavailable, one should be able to acquire it. If neither is possible, the simulation study eventually produces unreliable results. Then, the output is incomparable to the real system, which is critical for model validation.

1.6.2 Fundamental Steps of Simulation

- **Definition of Problem**

  The first step is to define the simulation's goals and determine the problem that needs solving. The problem can be further laid out by objectively observing the process under investigation. One should also take care and ascertain if the method of simulation is the appropriate one for the problem under investigation.

- **Project Planning & System Definition**

  Divide the project into work packages, and have the milestones clearly indicated for progress tracking of progress. This is crucial to ascertain if there is enough time & resources available for project completion. Definition of system involves identifying the components of a system that are to undergo modeling and the performance measures to be considered for analysis. This step requires skill to employ the appropriate level of detail & flexibility.

- **Formulation of Model**

  Understanding the behavior of the actual system chalking out the model’s basic needs is important in creating the appropriate one.

- **Collection & Analysis of Input Data**

  After model formulation, the type and quantum of data to be gathered is ascertained, which is then fitted to theoretical distributions.

- **Translation of Model, Verification & Validation**

  The model is translated into computing software. Verification process involves making certain that the model's behavior is as intended. This cab be done via animation or animation. It is important but not adequate. Thus, a model might be verified but may not be valid. Validation is used to ensure lesser or no significant deviation is there b/w the model and the system. This can be done through statistical analysis.

- **Experimentation & Subsequent Analysis**

  Experimental process involves creating alternative models, carrying out simulations, and statistically comparing its performance with that of the real system.

1.7 Objective of the Present Study

The following objectives have been considered in this study:

1. To experimentally determine water surface elevation due to flow over a broad-crested weir, at different locations in a channel.
2. To determine the value of coefficient of discharge (Cd) for a broad-crested weir.
3. To simulate the flow characteristics of broad-crested weir on HEC-RAS and ANSYS Fluent softwares.
4. To draw a comparative analysis and validate the experimentally obtained data with the simulation results from the computational softwares.

CHAPTER 2
Literature Review

Often, the indirect methods of measuring discharge are observed as the only practicable method to determine the peak magnitude of flood flow, past a certain site. These considerations are generally premised on the W.S. profile, that is typically defined from high-water marks, and on the channel's hydraulic properties. If there is a transition structure, an abrupt channel constriction, for instance, is used as a measurement device. The structure's geometry also influences the W.S. profile for a pre-defined flow rate measurement. As a result, knowing the H-Q relationship for a particular weir can be useful and may prove to be invaluable in determining an significant flood peak that couldn't otherwise be measured.

A large number of studies based on the flow over a broad-crested weir have been conducted:

- **2.1**

  Issam A. Al-Khatib (2014) worked on a project that predicted models for the discharge estimation in rect. b-crested weirs, by analyzing experimental results from flow of water over different weirs having varying dimensions of weir crest width & step height. The predictive capabilities of such models developed using multiple regression analysis. were then evaluated using the obtained experimental data.

- **2.2**

  Carlos A. Gonzaleza and Hubert Chanson (2007) laid out experiments in a nearly full-size broad-crested weir. For two configurations, detailed measurements for pressure & velocity were carried out. The results demonstrated the rapid flow distribution at the u/s end of the weir.

- **2.3**

Stefan Felder and Hubert Chanson (2012) carried out experiments on a large broad-crested weir having a rounded corner. For a variety of flow conditions, detailed free-surface, pressure and velocity measurements were undertaken. At high flow rates, the results revealed that at the u/s of the crested weir and near brink too, a rapid flow distribution was occuring.

The non-uniform velocity and non-hydrostatic pressure distributions were taken into account for analysis of the flow properties above the crest. The findings of the experiments shed new light on the vertical profiles of velocity & pressure on the crest, as well as on the flow patterns & boundary layers that developed. A slight inc. in the coefficient of discharge with an increasing head above the weir crest was observed. The boundary layer data demonstrated a reduction in the thickness of the boundary layer at the d/s end of the weir crest for the larger discharges.

- **2.4**

Shaymaa A. M. Al-Hashimi, Huda M. Madhloom , Rasul M. Khalaf, and Thameen N. Nahi (2017) used a computational fluid dynamic (CFD) model for simulating the flow over the broad-crested weirs. They measured the w.s. profile over the weir in a lab model & validated it using 2 D and 3D Fluent programmes. To estimate the water surface profile, the Navier-Stokes equations (a rapid flow distribution) were put together with the VOF method and the turbulent standard (k-e) model. The results were matched with experimental results to know the model's capability to describe the behavior of the w.s. profile over the b-crest weir. It is possible to construct a mathematical model with acceptable levels by using experimental data as validation . The two dimensional three dimensional simulation results agreed well with the experimental work.

- **2.5**

Sarker and Rhodes (2004) tested a 1D model of computational fluid dynamics software having complex areas of separated flow that impacted its hydrometric performance in the open channel flows, using the simple geometry of a rectangular b-crested weir. The results showed that the u/s water depth varied rapidly over the weir crest for a given flow rate.

- **2.6**

Kiumars Badr and Dariush Mowla (2014) investigated the effect of u/s steepening on the flow characteristics & the coefficient of discharge of a rectangular broad-crested weirs. Using a laboratory hydraulic flume, five weirs with weir angles 15, 30, 45, 60, and 90 degrees were made & the discharge coefficient of flow, negative velocity over the edge of weir crest, and w.s. profiles along the crest were evaluated. The experimental results demonstrated that upon decreasing the slope of the upstream side increases the weir's discharge efficiency and capacity. Based on the experimental results, it was made clear that using the weir with a slope of 15 degrees as opposed to the standard weir increased the discharge efficiency by up to 19.17 percent.

- **2.7**

The free w.s. profile of a rectangular broad-crested weir was determined using a Computational Fluid Dynamics model in conjunction with a laboratory model by Hossein Afshar, Seyed Hooman Hoseini (2013). To determine the water level profile & streamlines, simulations were carried out using the VOF free surface model and 3 turbulence models: RNG k–e, standard k–e, and LES.

The structured mesh having a high concentration in proximity to the solid regions was employed in the procedure. The results of the computation agreed well with the experimental data obtained in the lab. Furthermore, the results showed that the RNG model has the lowest level. All the turbulence methods were made use of in order to model w.s. profile over the weir, and a symmetric plan was selected to match the results from the experimental observation and simulation.

- **2.8**

Sargison and Percy (2009) studied flow over broad-crested, embankment weir of trapezoidal shape having varying slope at u/s and d/s. The authors showed the influence of slopes of 1H:1V, 2H:1V, and vertical in numerous combinations on these weir faces. Raising the u/s slope w.r.t to the vertical reduced the w.s. profile height and, as a result, the static pressure. The discharge coefficient was also reduced.

The w.s. and pressure profiles over the weir were unaffected by varying the downstream slope. Flow changes were restricted to the region d/s of the crest. It was demonstrated that a more gradual 2H:1V slope on the upstream weir face provided a higher coefficient of discharge than a 1:1 or vertical slope.

- **2.9**

Hazrat Amin, Mujahid Khan and Muhammad Ajmal (2019) presented a hydraulic comparison of two weir types: reinforced concrete and gabion. Varying hydraulic variables, such as downstream scouring, upstream sedimentation, coefficient of discharge, w.s. profiles along the weir & its foundation, were used to compare these weirs. Coefficient of discharge, scouring, and sedimentation were estimated using experimental analysis.

HEC-RAS was used to draw the water surface profile. According to the HEC-RAS results, the w.s. elevation for an RCC weir was found to be much higher than for a gabion. In comparison to the gabion weir, the RCC weir had a lower discharge coefficient. To summarize, concrete weirs were deemed more effective at raising water levels and decreasing seepage.

- **2.10**

Parhi et al. calibrated the channel roughness coefficient (Manning's n value) along the Mahanadi River in Odisha, India, using HEC-RAS. The authors decided that Manning's "n" value of 0.032 provides the optimum outcome for the Mahanadi river's Khairrmal to Munduli stretch. In terms of roughness of channel, the calibrated model was utilized to mimic the 2006 flood in the same reach. The Nash and Sutcliffe efficiency were used to evaluate calibrated and validated HEC-RAS-based model's performance.

- **2.11**

The study by Timbadiya (2011) aimed at determining values of Manning’s roughness coefficients for upper & lower reaches of the lower Tapi River for simulation of flood. The need for multiple channel roughness coefficients along the Tapi river were demonstrated by flood simulation using HEC-RAS. Timbadiya et al. (2012) also created a lower Tapi River integrated hydrodynamic model. The one-dimensional model hydrodynamic model was calibrated first for Manning's roughness of the river channel, and then the one-dimensional and two-dimensional integrated 11 hydrodynamic models were used to determine the sensitivity of Manning's 'n' on the lower Tapi river's coastal flood plain depth.

- **2.12**

Mehta et al. (2012) demonstrated an early design for the physical enhancement of the Tapi River's reach near the confluence of the Arabian Sea and the Tapi River in Surat City, Gujarat. The copeland method was used to design the table channel, which is included in the HEC-RAS model. Doiphode and Ravindra (2012) focused on the concepts of flood routing model, haing time-varying roughness to simulate flows in natural channels. Using the full dynamic wave theory & quasi-steady dynamic wave theory, the authors found solutions to Saint Venant's equation. A HEC-RAS unsteady flood modeling case study was carried out for the Kurundwad - Karad reach of the river Krishna.

- **2.13**

Sinha et al. (2010) used HEC-RAS and GIS to map flood hazards in the Kayu Ara river basin in Malaysia. The results of the study found that the size of precipitation events and the river basin land use development's state have a massively affect the pattern of hazard maps for river floods. In addition, the precipitation event's magnitude had a bigger effect on the hazard maps than the land use and development state for the Sungai-Kayu-Ara drainage basin.

- **2.14**

Using HEC-RAS software, Brych et al. (2002) generated flood hazard maps of urban areas in the Orlice valley of Czech Republic. The hydraulic model of the Orlice river system was calibrated by utilizing extreme floods. Al-Fahdawi (2009) used a numerical model for simulating the hydrodynamics of the Euphrates river between the Hathida dam and the Hit city. The author used the HEC-RAS model to calculate various parameters from a provided flood caused by a theoretical Hathidadam structural failure. In the Sebou basin in Northern Morocco.

- **2.15**

The behavior of water, free w.s. profiles, and velocity distributions of a b-crested weir having one opening, two vertically provided openings, and two horizontally provided openings were investigated by using 3D numerical modeling by Rasoul Daneshfaraz, Omar Minaei, Sorayya Dadashi & Amir Ghaderi (2021). They limited their study to these weir-opening arrangements. The numerical simulation results were compared to the experimental data in order to determine the most accurate of turbulence models. The RNG turbulence model was selected based on this comparison.

- **2.16**

Jihan Mahmood Qasim (2013) simulated free flow over a single-step, broad-crested weir, using HEC-RAS. The software computed the w.s. profile, located the hydraulic jump, & established the weir's head-discharge relationship. A series of lab measurements from a horizontal flume 5.0 meter long, 0.45 meter deep, and 0.30 meter wide confirmed the simulation results. The HEC-RAS software was found to capture with a reasonable accuracy, the overall features of the w.s. profile over the weir . The hydraulic jump's location could also be determined by it. A head-discharge relationship was also generated that was very close to the experimental data. Furthermore, HEC-RAS was observed to be simple to use for such a specific flow problem and to perform computations quickly.

- **2.17**

Jowhar R. Mohammed and Jihan M. Qasim (2012) compared 1D HEC-RAS with 2D A.D.H for flow over trapezoidal shaped broad-crested weirs. The models predicted the w.s. profile, locate where the hydraulic jump would occur, and establish the trapezoidal profile weir's head-discharge relationship. Several cases of free and steady water flow were investigated on short-crested and broad-crested weirs. The crest length, weir height, slope of weir face, flow rate, as well as the tailwater depth were all investigated.

Laboratory measurements on 27 weirs confirmed the simulation results. The largest deviation of the results from the measurements was detected in cases over short-crested weirs. Both HEC-RAS and ADH were found to slightly understate u/s water levels at lower flow rates & tailwater levels. Both computer programmes were observed to be capable of capturing the overall characteristics of the w.s. profiles with a reasonable level of accuracy. The ADH profiles were more informative. and this software was more accurate in finding the position of the hydraulic jump. HEC-RAS, on the other hand, better expressed the head-discharge relation.

- **2.18**

Sarker and Rhodes (2004) used the standard k-e turbulence closure model to conduct a numerical simulation of the flow over a broad-crested weir. The free-surface profiles so computed using the VOF method, were observed to agree with the measured results. Kirkgoz (2008) carried out experimental & numerical simulations of 2D free-surface flows interacting with rectangular & triangular b-crested weirs, using the standard k-e and standard k-w turbulence models. The numerical results showed that the values so predicted for the standard k-w turbulence model for the velocity field & free-surface profile, were in better agreement with experimentally measured values

CHAPTER 3
Usage of HEC-RAS Software

3.1 Overview

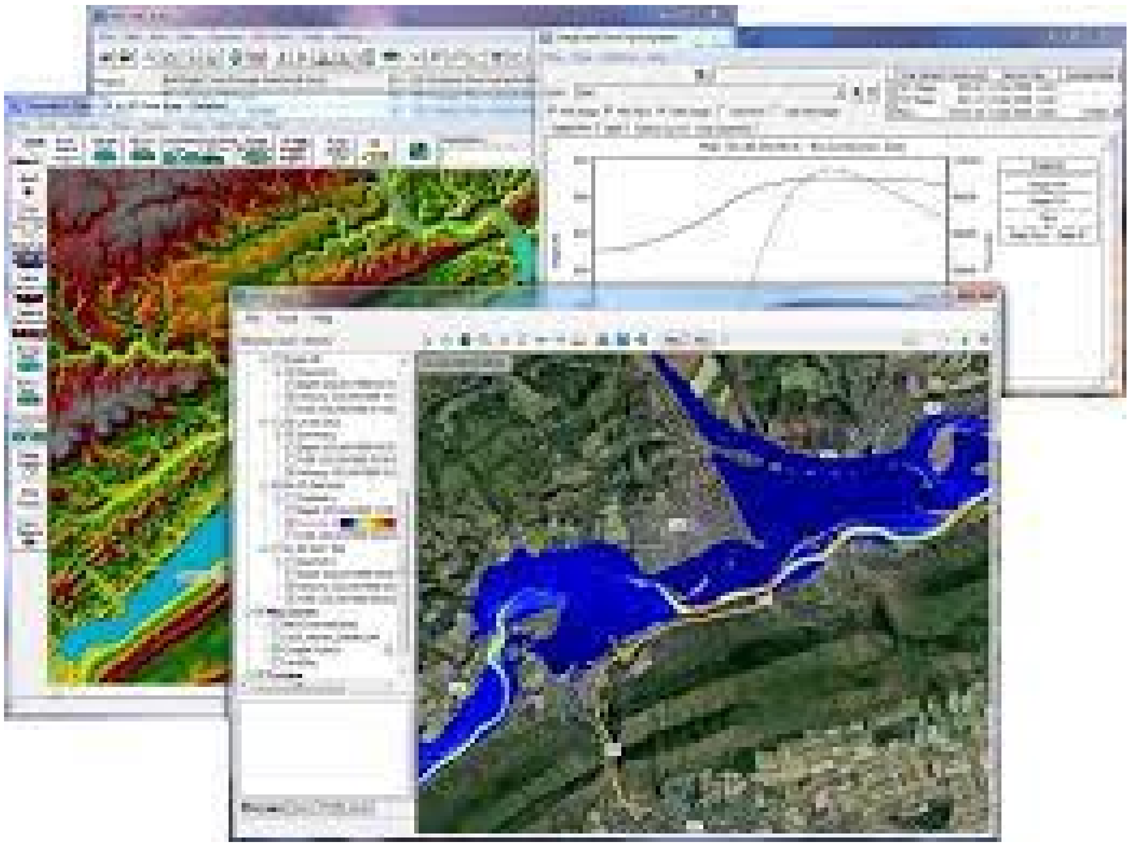


Fig 3.1 HEC-RAS Software
Source: HEC-RAS 6.0 manual

- HEC-RAS is widely used for the purpose of modeling the hydraulics of flow through water bodies including both natural lakes, & rivers, and artificially constructed channels in the field as well as laboratories. The River Analysis System (RAS) was developed by the Hydrologic Engg. Center (HEC) in CA, to aid water resource professionals, hydraulic engineers, academic researchers and students in the flow analysis of channels and determination of floodplain. The US Army Corps of Engineers (U.S.A.C.E.) of the United States Department of Defense (DoD) created the HEC-RAS software for the task of managing the rivers, harbors, and several other public water works that fall under their purview and jurisdiction.

- The HEC-RAS offers numerous capabilities for data entry, hydraulic analysis of channel components, data storage & management, graphing and output reporting. It has been utilized for modeling the water flowing through systems of open channels and for the computation of profiles of water surface.
- It also finds its particular application in the commercial sphere in the determination & management of floodplains and in flood insurance studies for the evaluation of floodway encroachments. Some additional uses include the designing & analysis of bridge and culverts, and studies pertaining to channel modification It can also be employed for analysis of dam breach.
- HEC-RAS supports calculations of water surface profile for both unsteady and steady flow. It also allows one to perform computations in sediment transport , as well as carry out water quality analysis of water bodies like ponds, lakes, streams and rivers. Inundation mapping is also a feature that can be performed using tools directly available inside the software.

3.2 Basic Components of the River Analysis System (RAS)

The HEC-RAS system contains the following river analysis components::

- Computations of water surface profiles for one-dimensional (1D) steady flow;
- Simulation of unsteady flow, both One-dimensional as well as two-dimensional
- Computations (in both 1D and 2D) for Quasi or fully unsteady flow, and sediment transport with movable boundary.
- 1D water quality analysis.

3.2.1 User Interface

It allows interaction with HEC-RAS software. Primary goal of its design is to make the software simple to use while ensuring high efficiency. The following functions are available through the UI:

- File management
- River analysis
- Entry/editing of data and geospatial data interfaces
- Display of input and output data, both via tabulation and graphical representation
- Inundation mapping & animations of the flow propagation
- Facilities for reporting

3.2.2 Steady Flow W.S. Profiles:

It calculates w.s. profiles for a steady GVF. It can handle a full network of channels, even a dendrite system, or a solo river reach. The steady flow component can model water surface profiles in the subcritical, supercritical, as well as mixed flow regimes. The solution of the one-dimensional energy equation is the foundation of the computational procedure. Contraction/expansion and Friction (from Manning's relation) are made use of to get energy losses. In situations where the profile exhibits RVF such as hydraulic jumps.

3.2.3 Graphics, Mapping and Output Capabilities

- X-Y plots, rating curves, cross-sections, W.S. profiles are among the graphical abilities of HEC-RAS. A 3D terrain plot and many of the simulation results are available too.
- The HEC-RAS Mapper is that component of the software which is used for mapping inundation.

- Output in tabular form is readily used. One could opt among several predefined tables or create custom-made tables. All this output can be printed, shown on screen, or passed on to other data-processing softwares such as Microsoft Word or Excel.

3.3 Basic Steps to Develop a Hydraulic Model using HEC-RAS

Four basic steps for HEC-RAS model:

- Start new project
- Geometric & flow data along with fixing boundary conditions
- Carrying out hydraulic calculations
- View and publish results

3.3.1 New Project

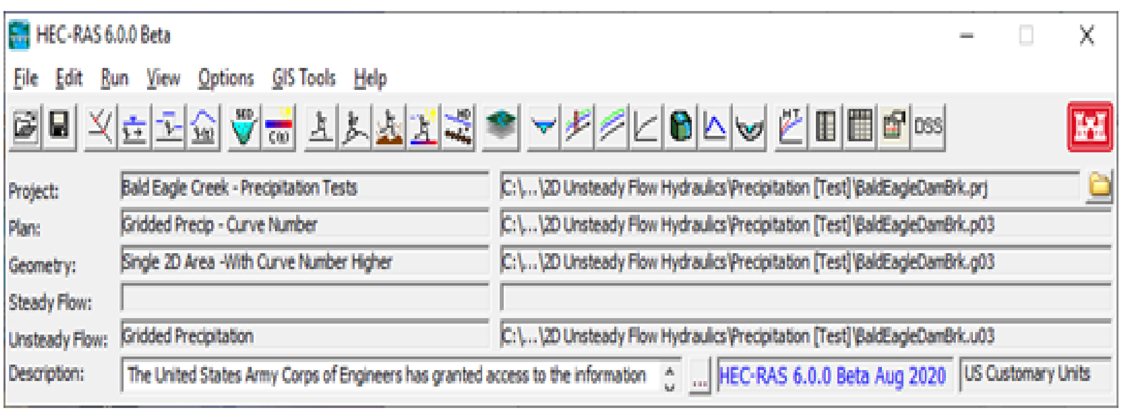


Fig 3.2 HEC-RAS Main Window

Source: HEC-RAS 6.0 Manual

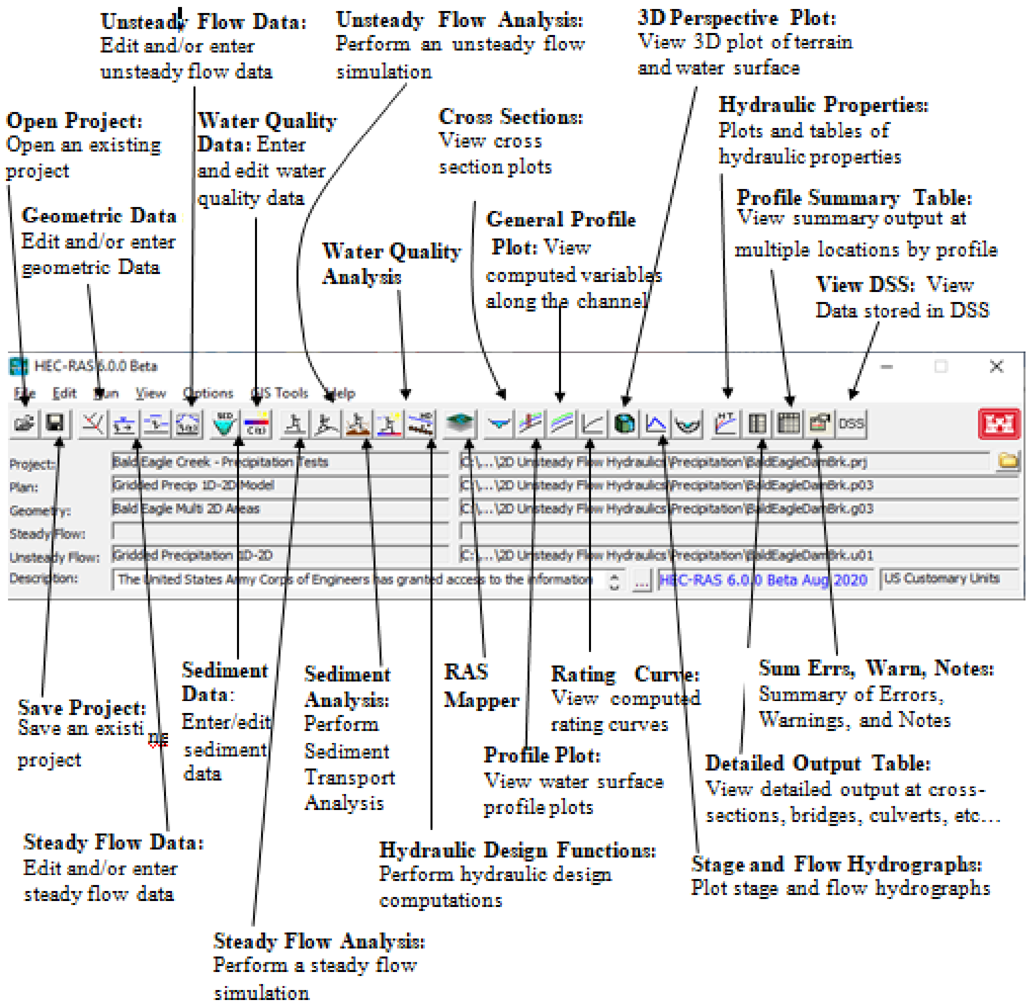


Fig 3.3 Various Menus in HEC-RAS Window

Source: Source: HEC-RAS 6.0 Manual

The top of the main main window in HEC-RAS has a Menu bar having these options:

- **File Menu**

  It includes: Creating a new project; Opening, Saving, Deleting existing one; Displaying summary of project, HEC-RAS data import; Generating Report; Exporting G.I.S Data; Exporting to HEC-DSS; Restoring Backup Data; Debugging Report, and Exit.

- **Edit**: It's for data entry/edit of Geometry, Steady Flow, Water Quality etc. .

- **Run**: It carries out hydraulic calculations. Under this, there are following menus included: Analysis of Steady Flow; Unsteady Flow; Quasi-Unsteady, Sediment; Water Quality, and Running of Multiple Plans.

- **View**: It consists of a set of features that give both tabular & graphical representation model output. It includes: General Profile Plot; Cross Sections; Rating Curves; W.S. Profiles; 3D Perspective Plots; Hydraulic Properties Plots; Stage and Flow Hydrographs; Profile Summary Tables; Detailed Output Tables; DSS Data; Unsteady Flow Spatial Plot; Summary Err, Warn, Notes; WQ Spatial Plot; Unsteady Flow Time Series Plot etc.

- **Options**: It allows changing the options of Programs setup; setting Default the Parameters; establishing Default Units (Metric or U.S.); Converting Project Units (Metric to U.S. Customary and vice-versa). The option of converting the Horizontal Coordinate System allows converting the entire project from one coordinate system to another.

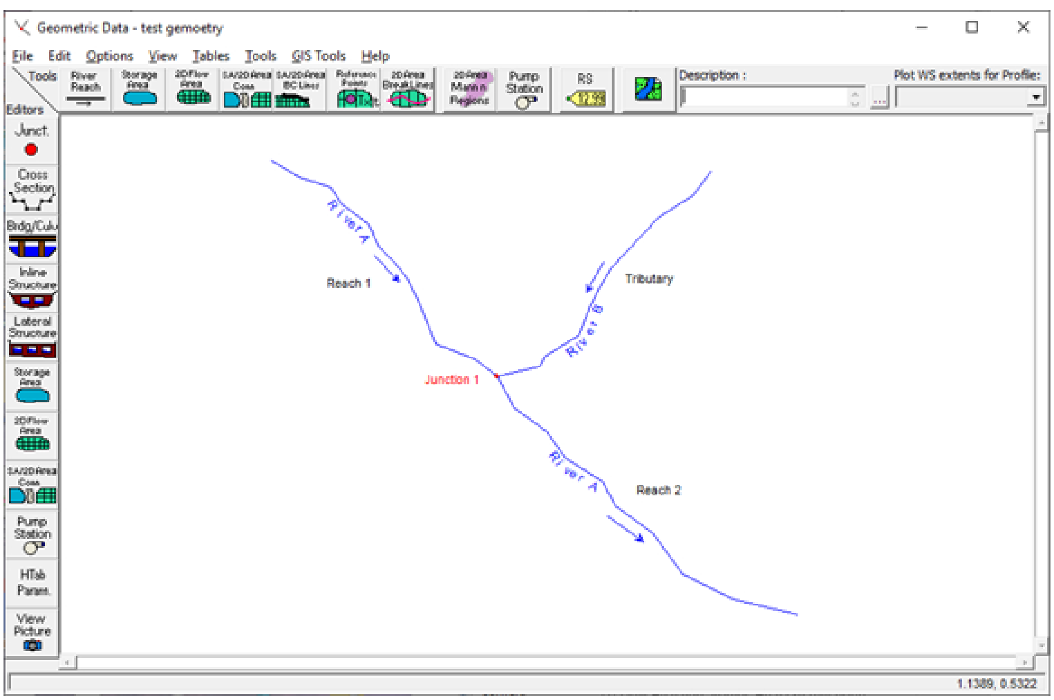


Fig 3.4 Geometric Data Window in HEC-RAS

Source: HEC-RAS 6.0 Manual

3.3.2 Geometric Data Entry

Prior to entering any Geometric data and Flow data, the Units System (U.S. Customary or Metric) is selected. from the Options menu of the main HEC- RAS window.

- To enter geometry, the Geometric Data editor is used.
- The Cross-Section option on the left of the Geometric data window causes the c/s editor to pop up.. Each c/s has the name of a River, Reach, River Station, & Description.
- River name, Reach name and River Station name are identifiers and they describe where the c/s is situated.

The required data for any c/s consists of the following:

- **Station-Elevation data**: C/S point coordinates.
- **Manning's n values**: There are numerous options for horizontal & vertical variations of the values.
- **Downstream reach lengths:** Distances from the current C/S to the next section downstream.
- **Main channel bank stations**: Left & right bank limits of the main channel.
- **Coefficients for Contraction & expansion** (default value is set to 0.1 & 0.3 respectively).

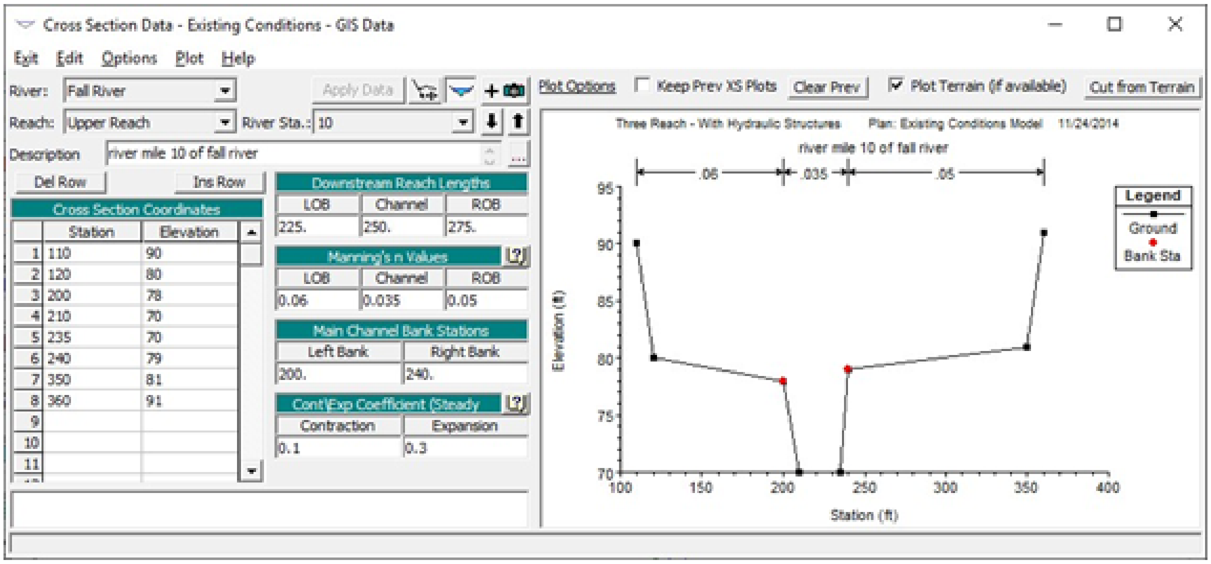


Fig 3.5 Cross Section Data of a typical HEC-RAS Project

Source: HEC-RAS 6.0 Manual

3.3.3 Entering Flow Data and Boundary Conditions

- The data for steady flow consists of: no. of profiles to be considered for computation, flow data, and boundary conditions in the river system.
- It is a must to enter at least one profile flow for every reach. Also, the flow cab be altered at any location within.
- For calculations, boundary conditions must be met. Only the d/s boundary conditions are required for a subcritical flow analysis. Only the u/s conditions are required for a supercritical flow analysis. For mixed-flow regime, both u/s & d/s boundary conditions are needed to be entered.
- After entering all of the steady flow data and boundary conditions, data is saved to a hard disk. Save Flow Data As from the File option on the Steady Flow Data menu will do this.

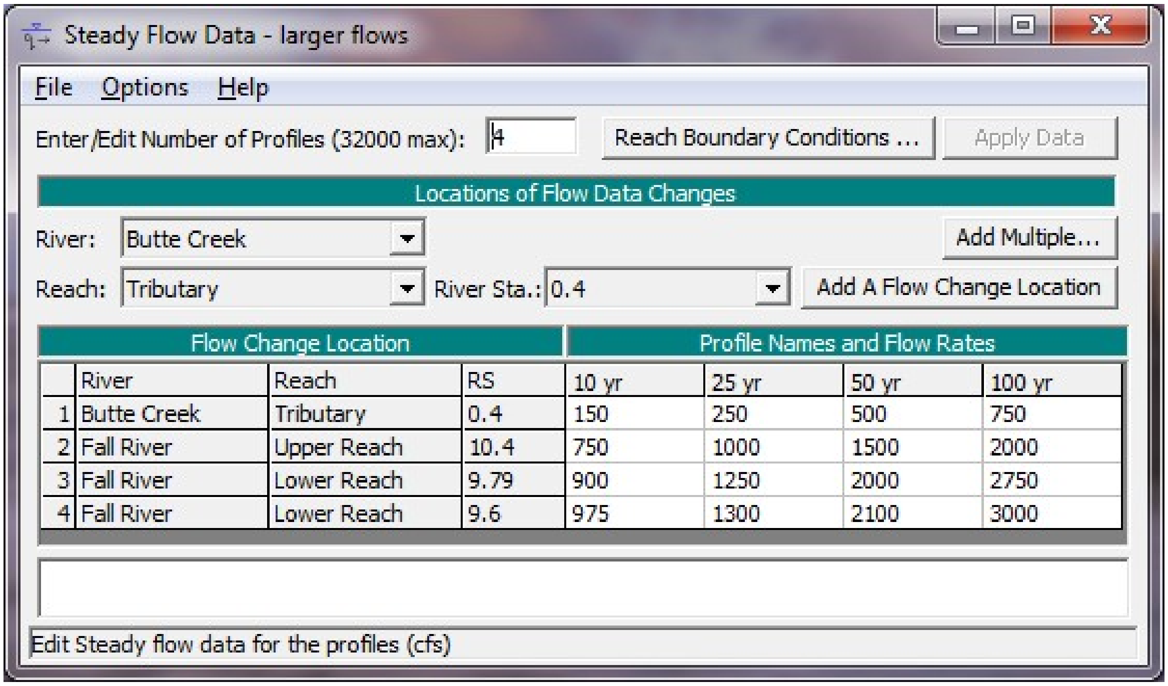


Fig 3.6 Steady Flow Data of a typical HEC-RAS Project

Source: HEC-RAS 6.0 Manual, 2021

3.3.4 Performing the Hydraulic Computations

- After entering all of the geometric and flow data, conducting hydraulic computation can begin. From the Run menu bar option on the main window, one can select any of the hydraulic analyses available.
- A Plan is created by choosing a set of geometric data & flow data.
- Then a Flow Regime is selected for which the HEC-RAS model will carry our computations.
- Calculations for subcritical, supercritical, & mixed flow regimes are there in the window.

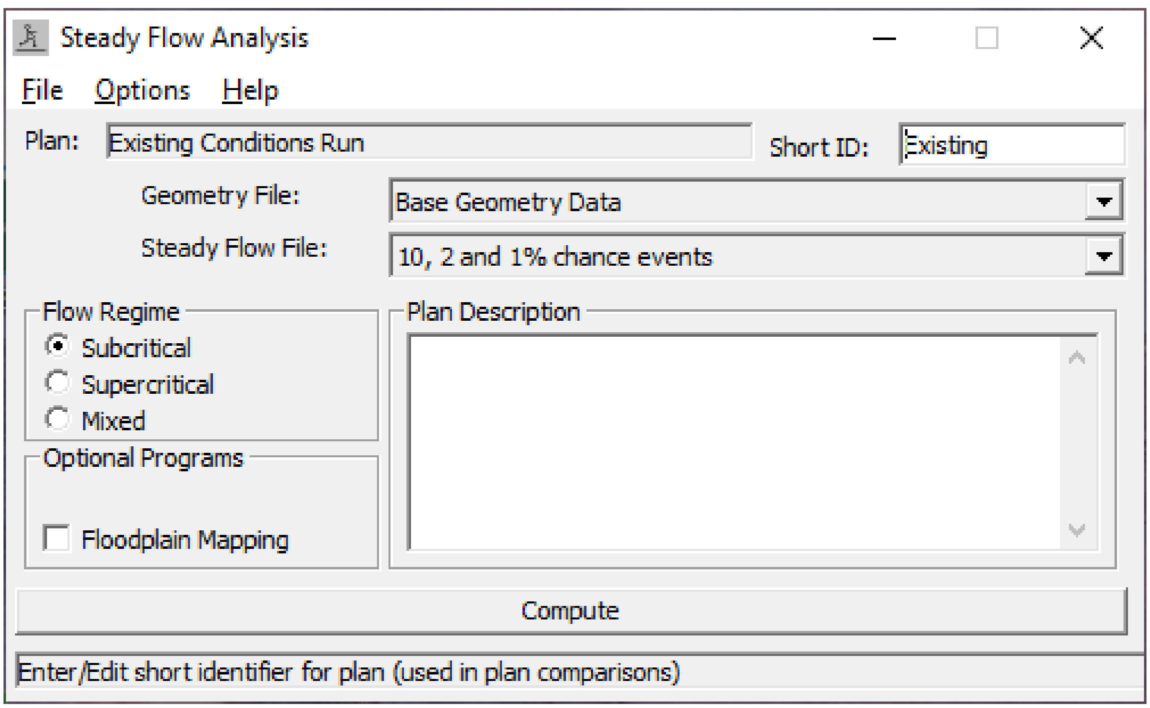


Fig 3.7 Steady Flow Analysis Window of a typical HEC-RAS Project
Source: HEC-RAS 6.0 Manual, 2021

- After a Plan is chosen and the calculation parameters have been chosen, one can run the steady flow computations by clicking the Compute button given at the bottom of the Steady Flow window.

- When this button is pressed, the HEC-RAS system bundles all of the input data for the chosen plan & writes it to a run file.
- Thereafter, the system runs the flow model & passes it to the name of the file.

3.3.5 Viewing and Printing of Results

Numerous output features include:

- C/S plots
- W.S.profile plots & General profile plots
- Rating curve plots
- 3D perspective plots
- tabular output for a specific location (given in Detailed Output Tables)
- tabular output for several locations (given in the Profile Summary Tables)
- A summary of warnings, errors, and notes is also given.

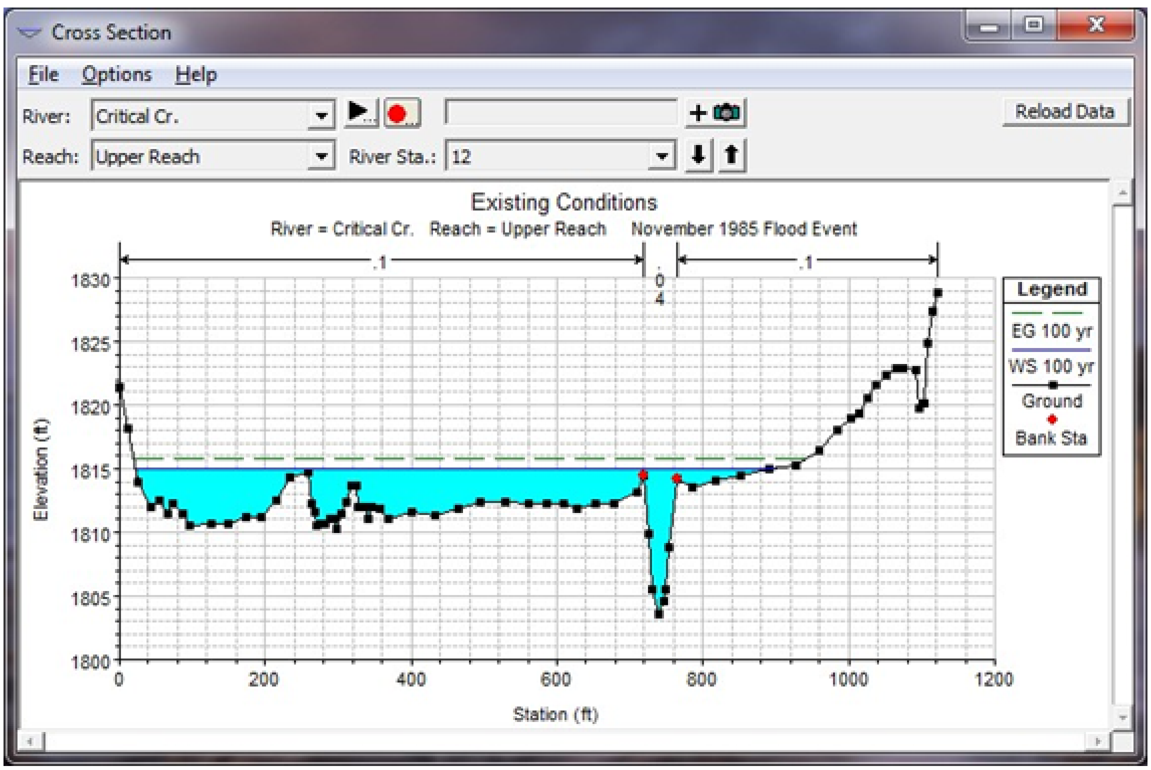


Fig 3.8 Cross Section Plot, of a typical HEC-RAS Project

Source: HEC-RAS 6.0 Manual, 2021

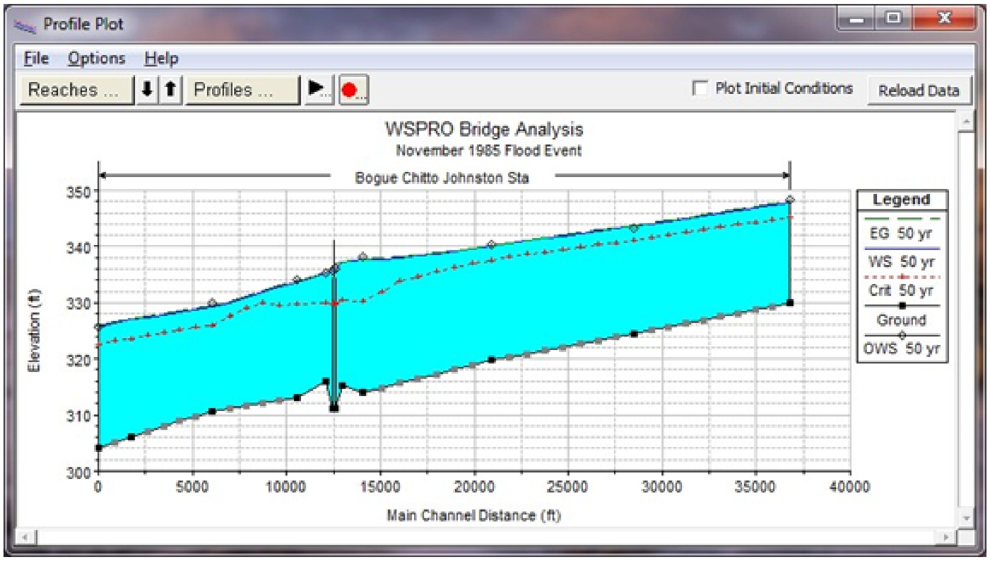


Fig 3.9 Profile Plot of a typical HEC-RAS Project

Source: HEC-RAS 6.0 Manual, 2021

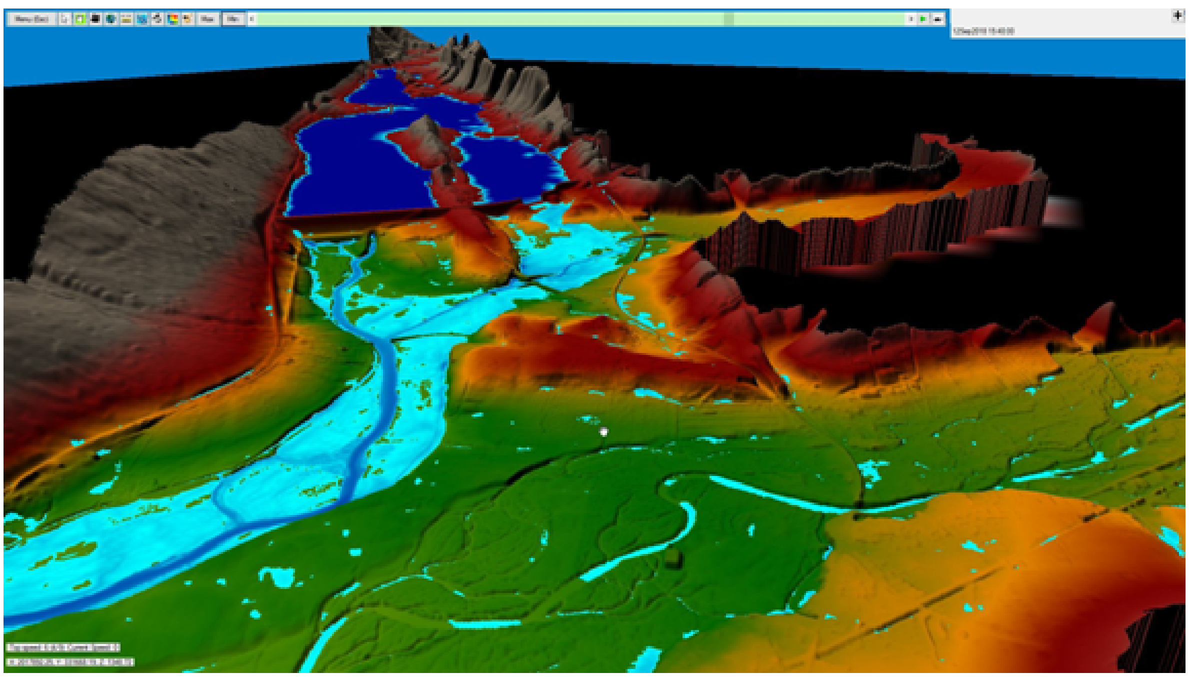


Fig 3.10 3D Perspective Plot of the Terrain and Water Depth in HEC-RAS Project

Source: HEC-RAS 6.0 Manual, 2021

CHAPTER 4
Methodology

4.1 Background Information

The experiment involving a series of discharge-runs was conducted on a rectangular flume using two models of broad-crested weirs as obstruction in the flume channel. The setup was located in the Hydraulics laboratory of the Civil Engineering Department, at Delhi Technological University.

The basic objectives of the experiment were three-fold: to demonstrate flow rate measurement, to ascertain the relationship between upstream head & flow rate in the water flowing over the broad-crested weir, and lastly to determine the discharge coefficient Cd. The data and readings obtained from the experiments were then utilized for performing flow simulation study on HEC-RAS and subsequently draw comparative analysis. The details of the apparatus involved in the experiment is illustrated in the following section of this chapter.

4.2 Experimental Setup

4.2.1 Tilting Rectangular Flume

- A rectangular flume (Model No. FM-01) having a structure housing of mild steel was used with a tilting wheel attached to the bottom so as to adjust the slope of the flume floor to a desired value. The upstream & downstream sections of the flume were provided with adjustable gates through a rack & pinion arrangement.
- For ease of visual observation of flow patterns along the flume, both sides of the flume were provided with a transparent Perspex sheet.
- Discharge of water can be collected by the help of a calibrated Orifice meter which is connected with 2 pressure gauges.
- The flume also consisted of control valves and a drain valve, a GI pipeline, and a mild steel sump tank at the outlet.

Fig 4.1 (i) & (ii): 4-m Tilting Rectangular Flume at Hydraulics Lab, DTU

Source: Self

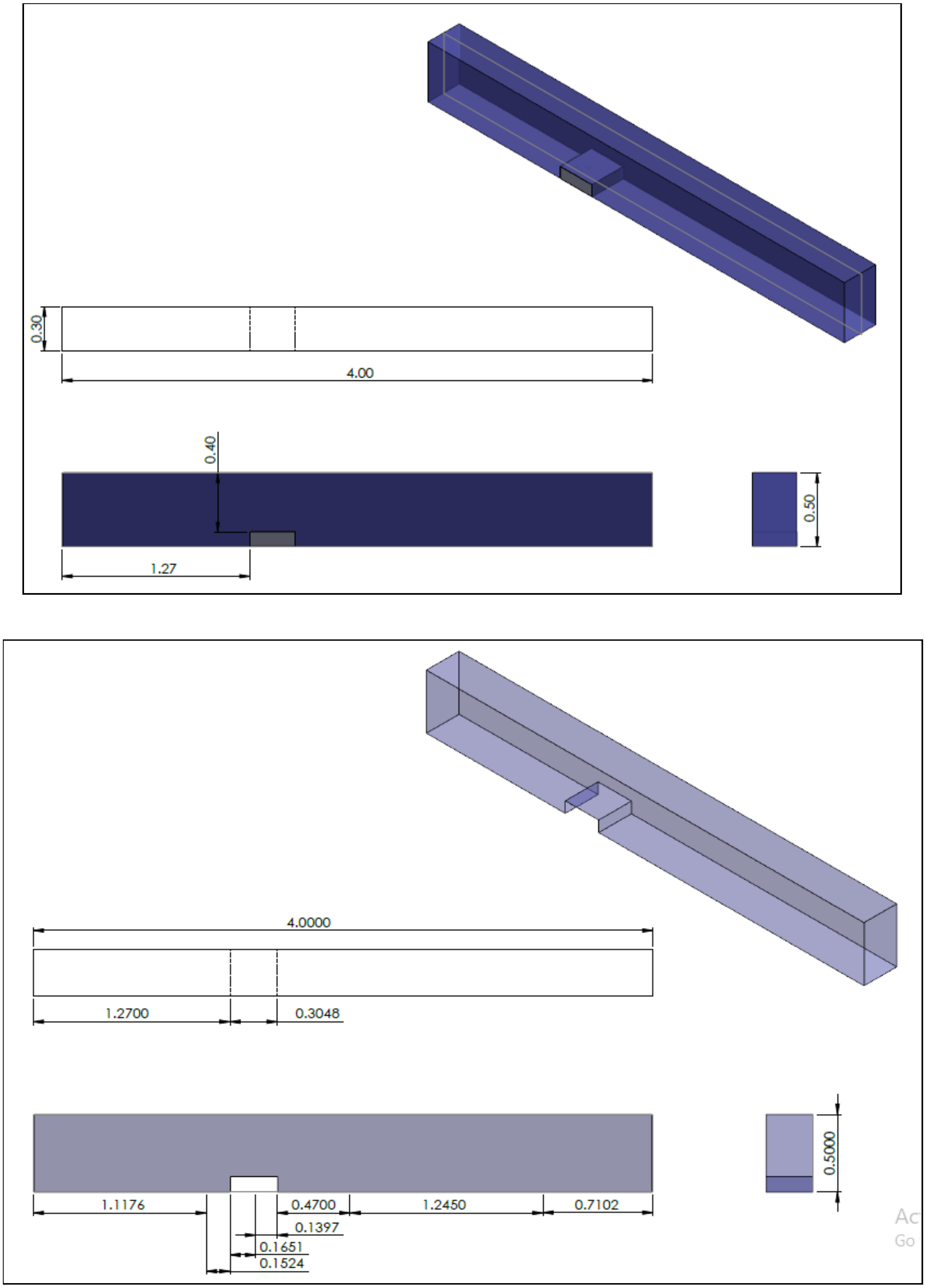


Fig 4.2 3D Diagrams of the Flume and Weir Arrangement (created on Solidworks)

The basic dimensions of the flume are as follows:

- Length: 4.0 meters
- Width: 30.5 cm (0.305 meters)
- Depth: 50 cm (0.5 meters)

4.2.2 Broad-Crest Weir Models

The experiment made use of two types of broad-crested weir: one having vertical u/s and d/s faces, while the other having sloping sides with ratio 0.4H : 1V.

Fig 4.3 (i) & (ii): B-Crested Weir with Vertical faces and sloping faces

Source: Self

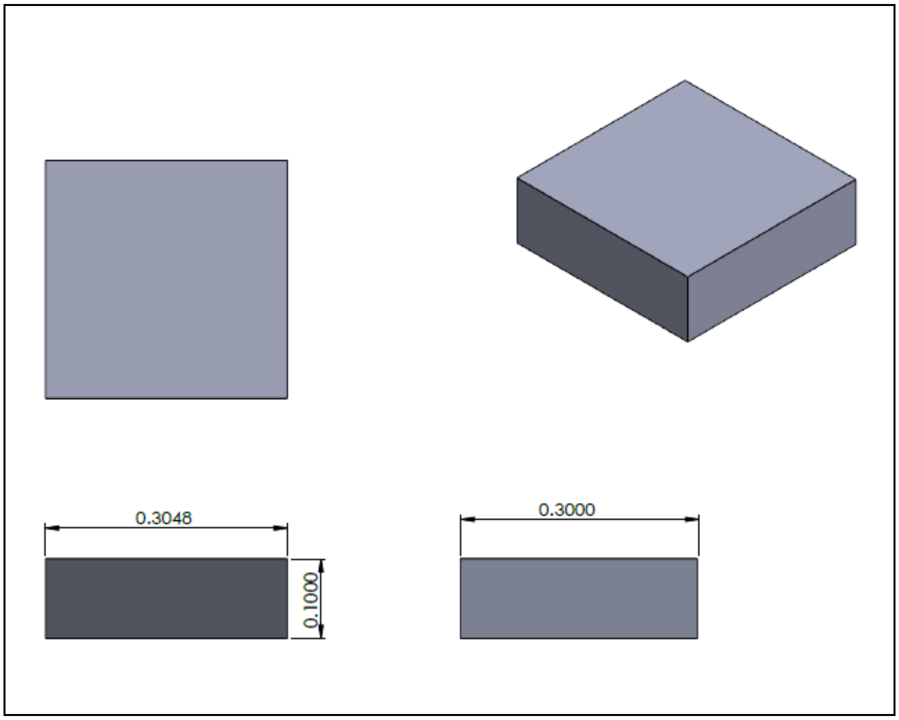


Fig 4.4 3D Model of Weir with vertical faces (created on Solidworks)

Source: Self

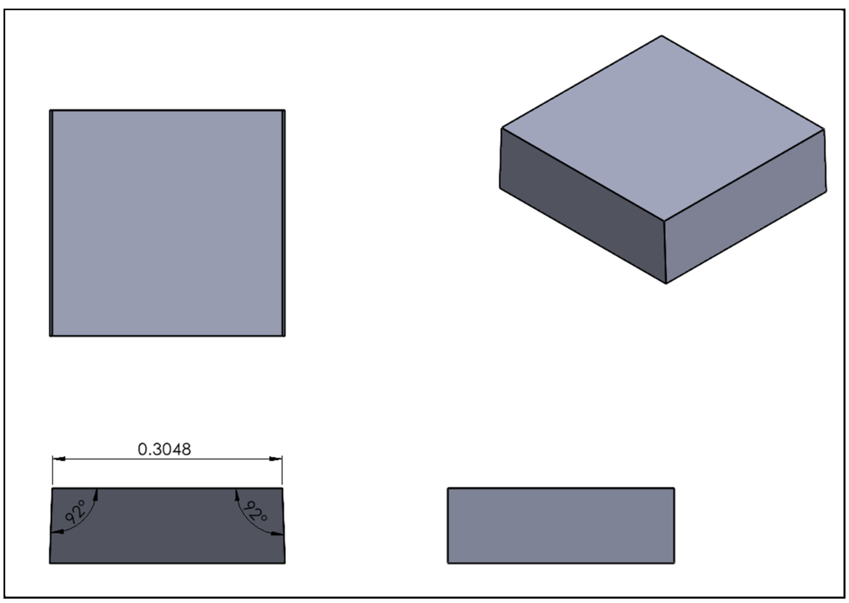


Fig 4.5 3D Model of Weir with Sloping faces (created on Solidworks)

Source: Self

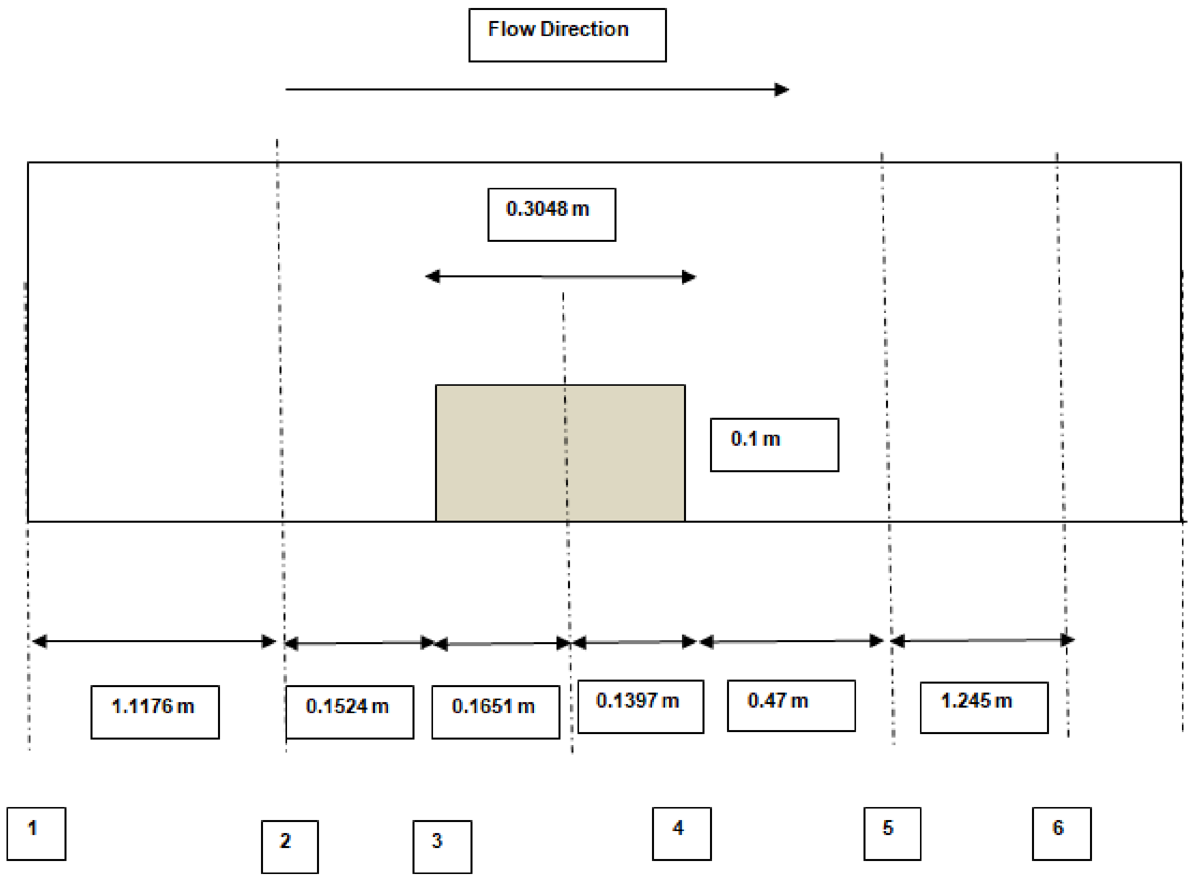


Fig 4.6: 2D Schematic Diagram of Flume and Weir Arrangement

Sections are named as follows:

- Section1: Entry Gate of Flume
- Section 2: U/S Head Measurement Point
- Section 3: U/S Face of the Weir
- Section 4: D/S Face of the Weir
- Section 5: D/S Head Measurement Point
- Section 6: Exit Gate of Flume

4.2.3 Movable Vernier Gauge

It consisted of a vernier gauge (least count 0.01) attached to a long metal needle used to measure the height of the water surface, movable throughout the length of the flume. Main scale was given in millimeters (mm). The Vernier scale was designed such that ten divisions in the Vernier scale corresponded to nine divisions in the main scale.

4.2.4 Additional Apparatus

It included:

- Power Supply (Three Phase, 440 V, 50 Hz)
- Collecting tank for Discharge Measurement
- Stopwatch

4.3 Procedure

- The channel was adjusted so as to keep the channel bed horizontal. The broad-crested weir model was placed carefully inside the channel and sealed in order to avoid leakage.
- The pump was turned on and the channel was filled with water upto the weir crest level & reading on the point gauge was noted.
- The flow regulating valve was adjusted so as to provide maximum possible discharge without flooding the flume.
- Conditions were allowed to steady before the water surface heights at predefined points were measured along with the discharge.
- The discharge was reduced in stages and a series of readings of Q and H were noted.
- Above process was repeated for another model.

- For each iteration, the actual discharge was measured using the volumetric tank of capacity 0.05 cubic meters. The discharge value was calculated by noting the time taken to fill the tank.

4.4 Experimental Observations

As mentioned earlier, two types of broad crested weirs were used. Further, in addition to the discharge runs performed with the flume kept in horizontal position, observations were also made by tilting the flume at 2 percent slope w.r.t. the horizontal.

4.4.1 Broad-Crested Weir with Vertical Faces

- Length of Weir, L (m) = 0.3 m
- Width of Weir, Bw (m) = 0.3 m
- Height of Weir (m) = 0.1 m
- Point Gauge Reading from floor of the Flume (m) = 0.3204
- Point Gauge Reading from top of Weir crest (m) = 0.4255
- Volume of Collecting Tank for Discharge Measurement (m^3) = 0.05 m^3
- Area of the upstream face = 0.03 m^2
- Distance of point for U/S head measurement from face of weir = 0.1524 m
- Distance of point for D/S head measurement from face of weir = 0.47 m

Formulas to be used:

- $Q_{theoretical}$ (m^3/s) = 2/3 * Cd * $(2g)^{0.5}$ * L * $H^{1.5}$
- Q_{actual} (m^3/s) = Volume of tank / Time
- Coefficient of Discharge, C_d = Actual DIscharge/Theoretical Discharge

  = $Q_{theoretical}$ / Q_{actual}
- Average Velocity (m/s) = Q_{actual} / Area of weir face

  = (Q_{actual}/ 0.05) m/s

(a) Observations for Horizontal Configuration of Flume

S.No.	Reading of W.S. Elevation U/S of Weir (m)	U/S Height Above Floor of Flume (m)	Reading W.S. Elevation above Weir (m)	Height above crest (m)	Reading of W.S. Elevation D/S of Weir (m)	D/S Height above Floor of flume (m)	U/S Height of W.S. Elevation above Weir Crest, H_1 (m)
1	0.4381	0.1177	0.4379	0.0124	0.3245	0.0041	0.0126
2	0.4603	0.1399	0.4444	0.0189	0.3277	0.0073	0.0348
3	0.4641	0.1437	0.4465	0.021	0.3302	0.0098	0.0386
4	0.4644	0.144	0.4468	0.0213	0.3304	0.01	0.0389
5	0.4706	0.1502	0.4497	0.0242	0.3311	0.0107	0.0451
6	0.4715	0.1511	0.4505	0.025	0.3329	0.0125	0.046
7	0.4745	0.1541	0.4521	0.0266	0.3347	0.0143	0.049
8	0.4773	0.1569	0.4677	0.0422	0.3361	0.0157	0.0518

Table 4.1 Observations for Weir Having Vertical face in Horizontal Configuration of Flume

S.No.	Theoretical Discharge, Q(th) (m3/s)	Time taken for filling 0.05 m3 tank (seconds)	Actual Discharge, Q(a) (m3/s)	Value of Cd = Q(a) / Q(th)	Avg. Velocity over Weir (m/s)
1	0.001252954542	24.2	0.002066115702	1.648994942	0.04176515141
2	0.005751066152	16.1	0.003105590062	0.5400024935	0.1917022051
3	0.006718316416	12.87	0.003885003885	0.5782704541	0.2239438805
4	0.006796790742	12.91	0.003872966692	0.5698228531	0.2265596914
5	0.008484852754	9.27	0.005393743258	0.6356908498	0.2828284251
6	0.008740096842	8.24	0.006067961165	0.6942670402	0.2913365614
7	0.009608898751	7.92	0.006313131313	0.6570088287	0.320296625
8	0.01044417492	7.34	0.006811989101	0.6522285535	0.348139164

Table 4.1 (continued)

Average Value of Cd = 0.61251

(b) Observations for Flume at a Slope of 2 percent

S.No.	Reading of W.S. Elevation U/S of Weir (m)	U/S Height Above Floor of Flume (m)	Reading W.S. Elevation above Weir (m)	Height above crest (m)	Reading of W.S. Elevation D/S of Weir (m)	D/S Height above Floor of flume (m)	U/S Height of W.S. Elevation above Weir Crest, H_1 (m)
1	0.4521	0.1317	0.4419	0.0164	0.3262	0.0058	0.0266
2	0.4577	0.1373	0.4445	0.019	0.3266	0.0062	0.0322
3	0.4613	0.1409	0.4458	0.0203	0.3288	0.0084	0.0358
4	0.4638	0.1434	0.4497	0.0242	0.3319	0.0115	0.0383
5	0.465	0.1446	0.4507	0.0252	0.3331	0.0127	0.0395
6	0.4686	0.1482	0.4519	0.0264	0.3346	0.0142	0.0431

Table 4.2 Observations for Weir Having Vertical face at 2 % slope of Flume

S.No.	Theoretical Discharge, Q(th) (m3/s)	Time taken for filling 0.05 m3 tank (seconds)	Actual Discharge, Q(a) (m3/s)	Value of Cd = Q(a) / Q(th)	Avg. Velocity over Weir (m/s)
1	0.003843279347	16.13	0.003099814011	0.8065544373	0.1281093116
2	0.005118742759	13.94	0.003586800574	0.7007190521	0.1706247586
3	0.006000729321	12.72	0.00393081761	0.655056644	0.2000243107
4	0.006640146453	10.63	0.004703668862	0.7083682408	0.2213382151
5	0.006954647791	9.74	0.005133470226	0.7381351838	0.231821593
6	0.007926754401	9.42	0.005307855626	0.6696127264	0.2642251467

Table 4.2 (continued)

Average Value of Cd = 0.71307

4.4.2 Broad-Crested Weir with Sloping Faces

- Length of Weir, L (m) = 0.3 m
- Width of Weir, Bw (m) = 0.3 m
- Height of Weir (m) = 0.1 m
- Point Gauge Reading from floor of the Flume (m) = 0.3203
- Point Gauge Reading from top of Weir crest (m) = 0.4185
- Volume of Collecting Tank for Discharge Measurement (m^3) = 0.05 m^3
- Area of the upstream face = 0.03 m^2
- Distance of point for U/S head measurement from face of weir = 0.1124 m
- Distance of point for D/S head measurement from face of weir = 0.43 m

Formulas to be used:

- $Q_{theoretical}$ (m^3/s) = 2/3 * Cd * $(2g)^{0.5}$ * L * $H^{1.5}$
- Q_{actual} (m^3/s) = Volume of tank / Time
- Coefficient of Discharge, C_d = Actual DIscharge/Theoretical Discharge

  = $Q_{theoretical}$ / Q_{actual}

- Average Velocity (m/s) = Q_{actual} / Area of weir face

  = (Q_{actual}/ 0.05) m/s

(c) Observations for Horizontal Configuration of Flume

S.No.	Reading of W.S. Elevation U/S of Weir (m)	U/S Height Above Floor of Flume (m)	Reading W.S. Elevation above Weir (m)	Height above crest (m)	Reading of W.S. Elevation D/S of Weir (m)	D/S Height above Floor of flume (m)	U/S Height of W.S. Elevation above Weir Crest, H_1 (m)
1	0.4394	0.1286	0.4282	0.0137	0.3234	0.003	0.0249
2	0.4443	0.1335	0.4319	0.0174	0.3253	0.0049	0.0298
3	0.4488	0.138	0.4335	0.019	0.3276	0.0072	0.0343
4	0.4557	0.1449	0.4358	0.0213	0.3299	0.0095	0.0412
5	0.4584	0.1476	0.4359	0.0214	0.3318	0.0114	0.0439
6	0.4603	0.1495	0.4381	0.0236	0.3326	0.0122	0.0458

Table 4.3 Observations for Weir Having Sloping face in Horizontal Configuration of Flume

S.No.	Theoretical Discharge, Q(th) (m3/s)	Time taken for filling 0.05 m3 tank (seconds)	Actual Discharge, Q(a) (m3/s)	Value of Cd = Q(a) / Q(th)	Avg. Velocity over Weir (m/s)
1	0.003480795572	23.82	0.002099076406	0.6030450117	0.1160265191
2	0.00455726091	18.95	0.002638522427	0.5789711143	0.151908697
3	0.005627567039	17.3	0.00289017341	0.5135742303	0.187585568
4	0.007408415321	12.13	0.004122011542	0.5563958502	0.2469471774
5	0.008148473876	10.82	0.004621072089	0.5671089039	0.2716157959
6	0.008683158212	10.31	0.004849660524	0.5585134355	0.2894386071

Table 4.3 (continued)

Average Value of Cd = 0.562934758

(d) Observations for Flume at a Slope of 2 percent

S.No.	Reading of W.S. Elevation U/S of Weir (m)	U/S Height Above Floor of Flume (m)	Reading W.S. Elevation above Weir (m)	Height above crest (m)	Reading of W.S. Elevation D/S of Weir (m)	D/S Height above Floor of flume (m)	U/S Height of W.S. Elevation above Weir Crest, H_1 (m)
1	0.1177	0.4298	0.0142	0.3251	0.0066	0.0225	0.1177
2	0.1209	0.4302	0.0146	0.3266	0.0081	0.0257	0.1209
3	0.1283	0.4347	0.0191	0.3288	0.0103	0.0331	0.1283
4	0.1325	0.4366	0.021	0.3304	0.0119	0.0373	0.1325
5	0.1361	0.4387	0.0231	0.3326	0.0141	0.0409	0.1361
6	0.1394	0.4403	0.0247	0.3341	0.0156	0.0442	0.1394

Table 4.4 Observations for Weir Having Vertical face at 2% slope of Flume

S.No.	Theoretical Discharge, Q(th) (m3/s)	Time taken for filling 0.05 m3 tank (seconds)	Actual Discharge, Q(a) (m3/s)	Value of Cd = Q(a) / Q(th)	Avg. Velocity over Weir (m/s)
1	0.00298987667	17.92	0.002790178571	0.9332085834	0.09966255566
2	0.00364988501	15.86	0.00315258512	0.8637491623	0.1216628337
3	0.005334841094	12.96	0.003858024691	0.7231751843	0.1778280365
4	0.006381793464	11.14	0.004488330341	0.7033023501	0.2127264488
5	0.007327645644	10.23	0.004887585533	0.6670062624	0.2442548548
6	0.008232142911	9.35	0.005347593583	0.6495992163	0.2744047637

Table 4.4 (continued)

Average Value of Cd = 0.760383019

CHAPTER 5

Simulation Performed on HEC-RAS

5.1 Approach I: With Inline Structure

In this approach, simulation was performed by adding an inline structure between Cross Sections 4 and 3 of the River reach. The essential steps and results are displayed in the following sections of this chapter:

5.1.1 River Reach

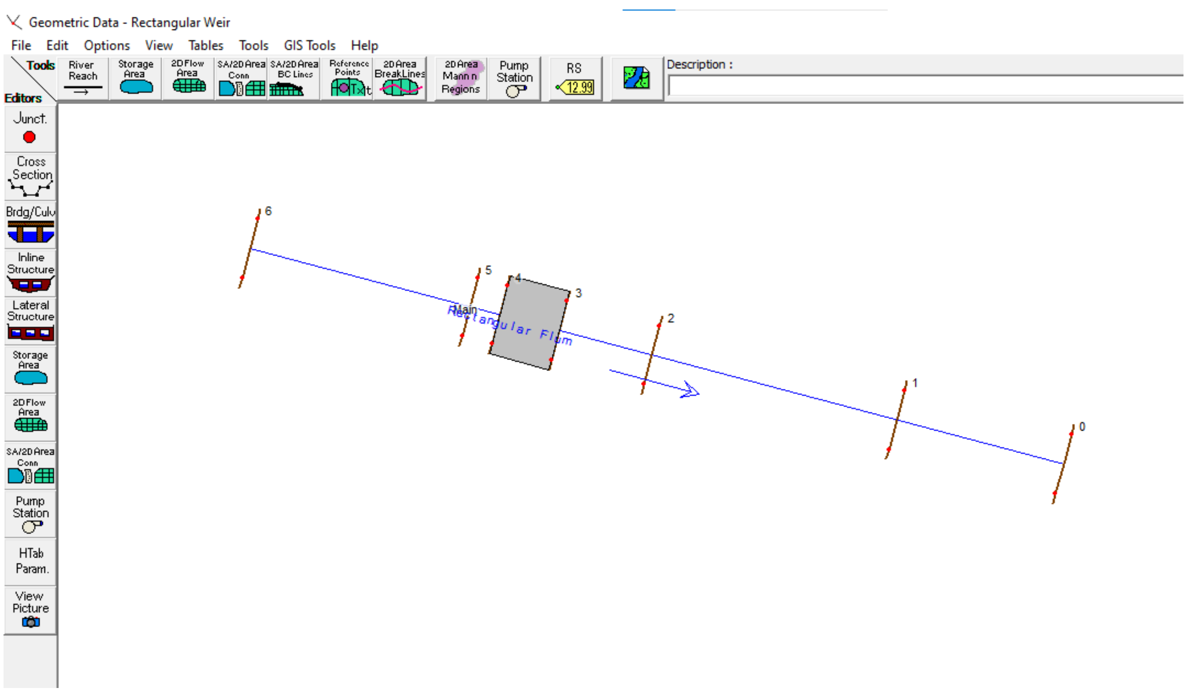


Fig 5.1 River Reach for Rectangular Weir (Vertical Sides)

5.1.2 Cross Section Data Entry

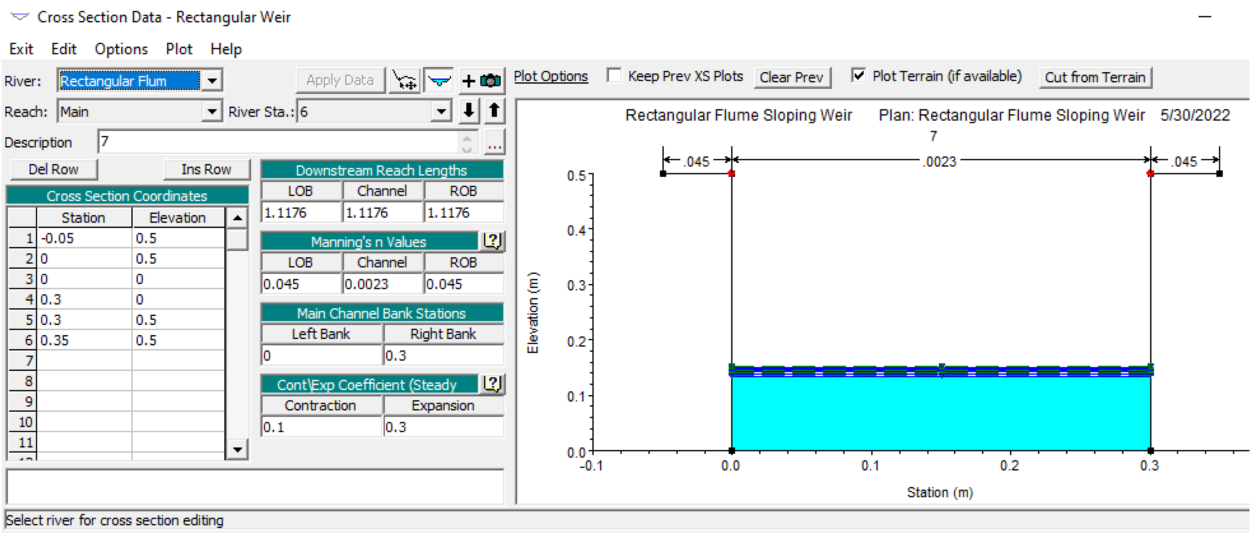


Fig 5.2 C/S Data Entry for Rectangular Weir (Vertical Sides)

5.1.3 Inline Structure Data

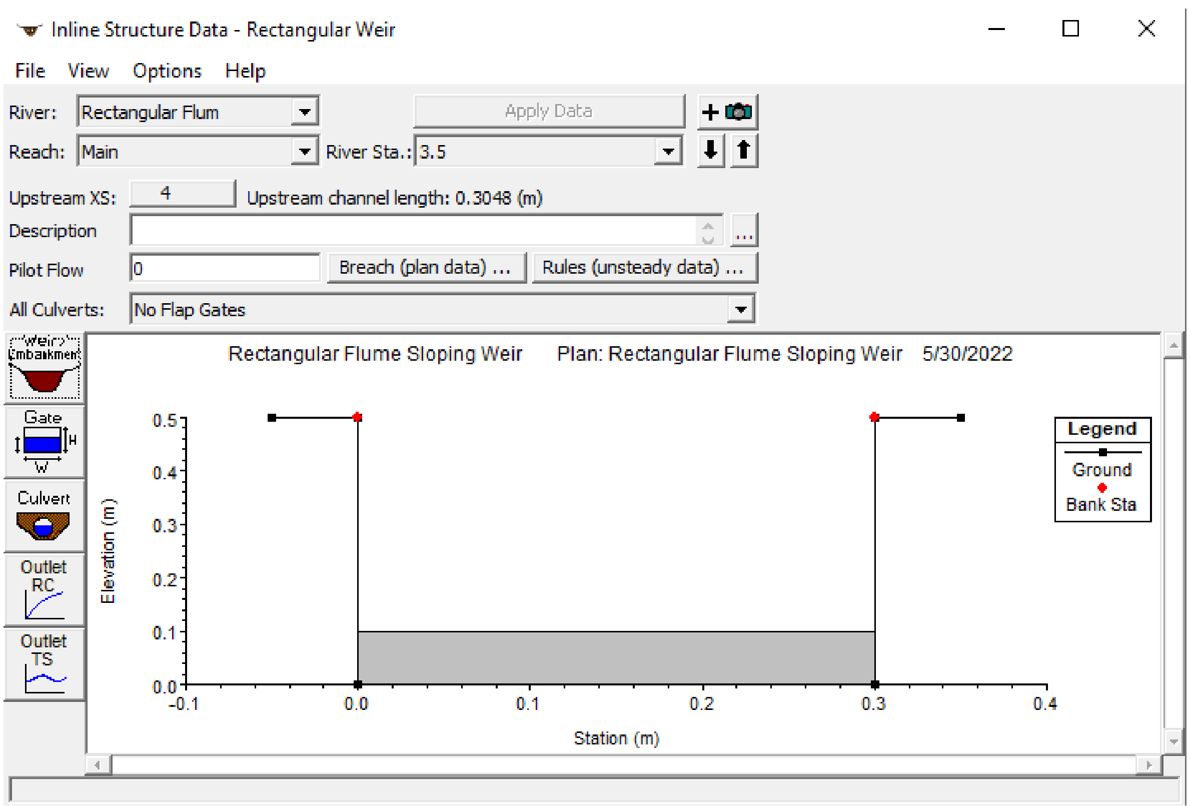


Fig 5.3 Inline Structure Data Entry Rectangular Weir (Vertical Sides)

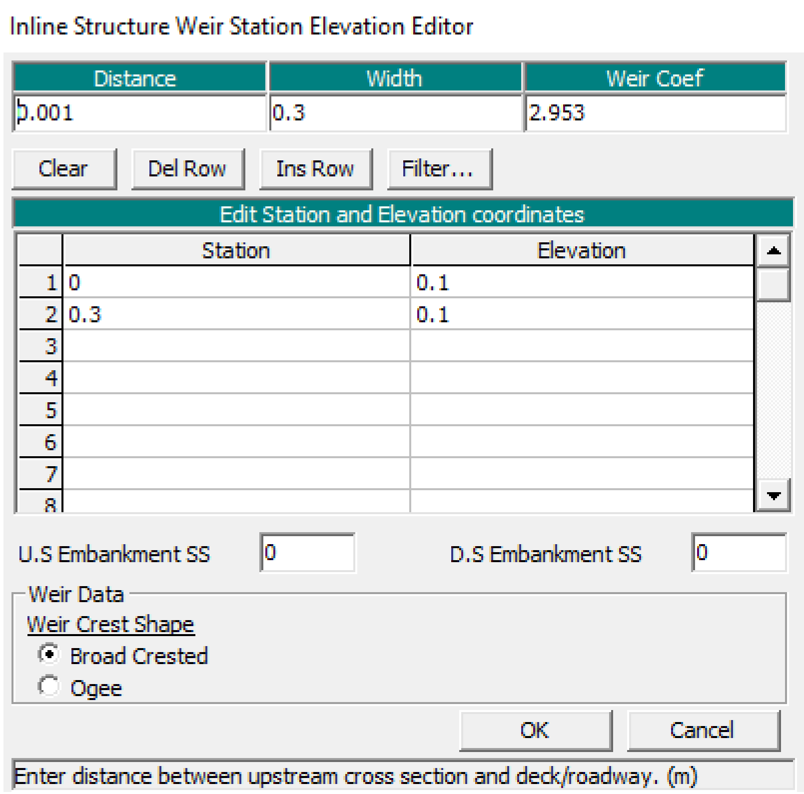


Fig 5.4 Inline Structure Station Elevation Editor for Rectangular Weir (Vertical Sides)

5.1.4 Steady Flow Data Entry and Analysis

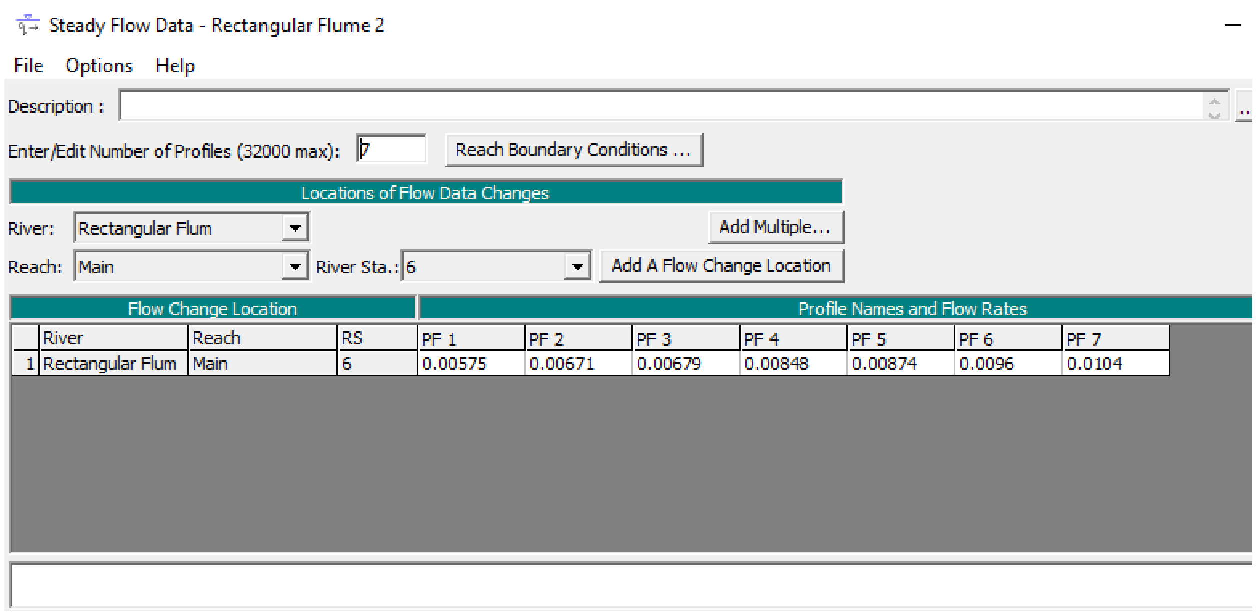


Fig 5.5 Steady Flow Data Entry for Rectangular Weir (Vertical Sides)

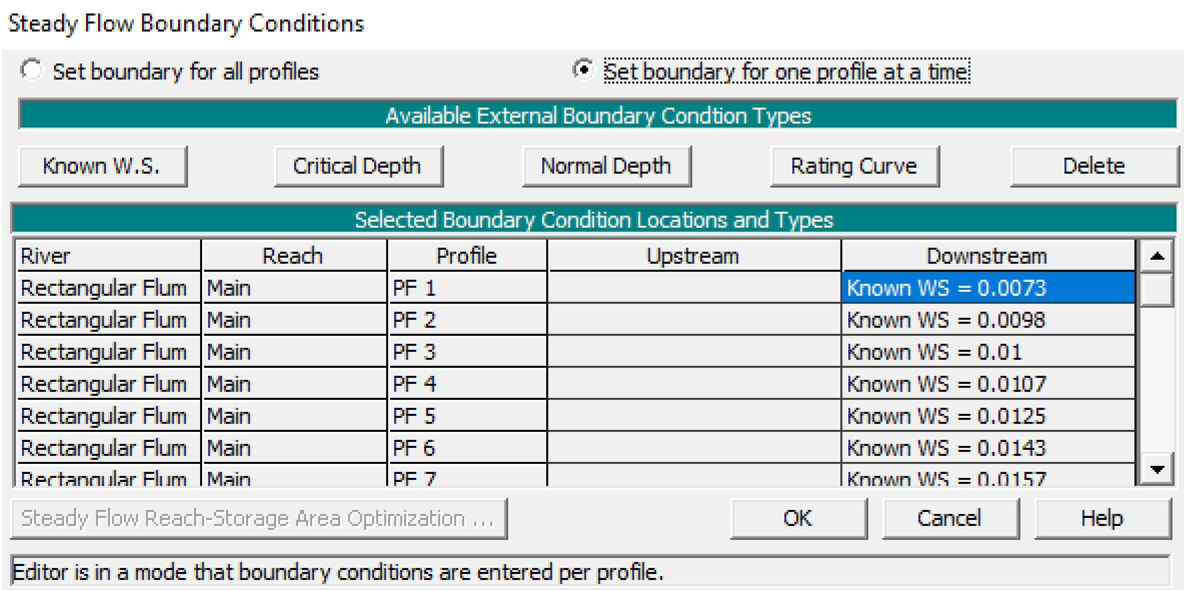


Fig 5.6 Steady Flow Boundary Conditions Entry for Rectangular Weir (Vertical Sides)

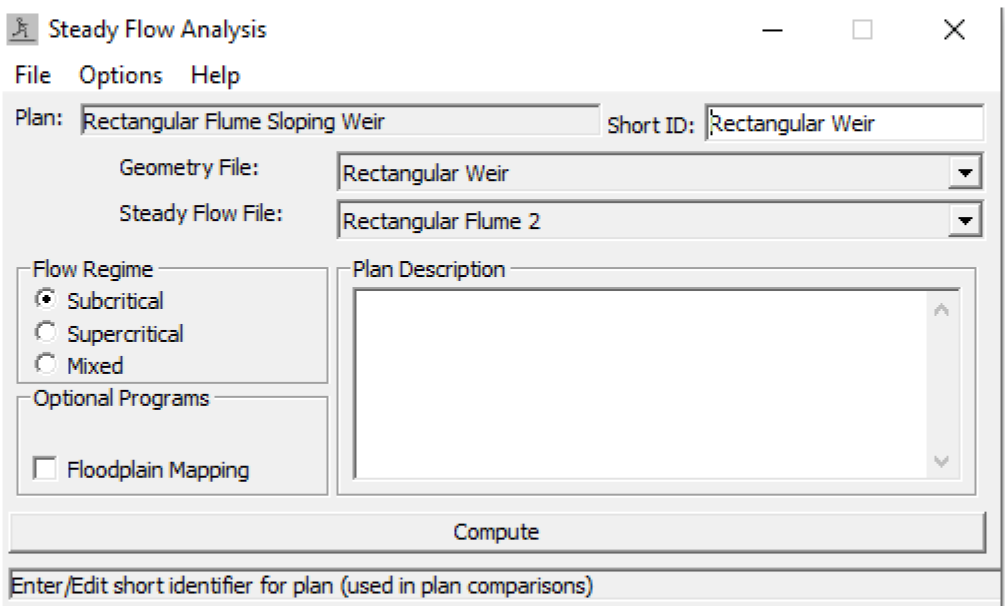


Fig 5.7 Steady Flow Analysis performed for Rectangular Weir (Vertical Sides)

5.1.5 Output Results for Approach I

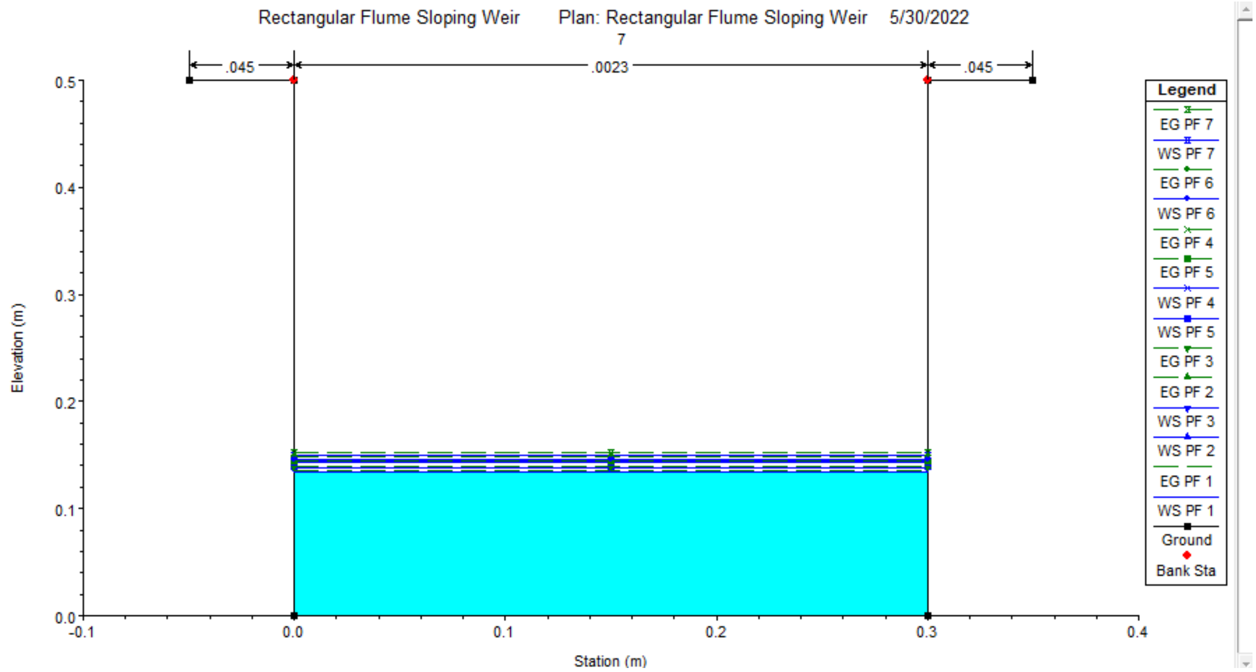


Fig 5.8 Cross Section of U/S Head Measurement Point

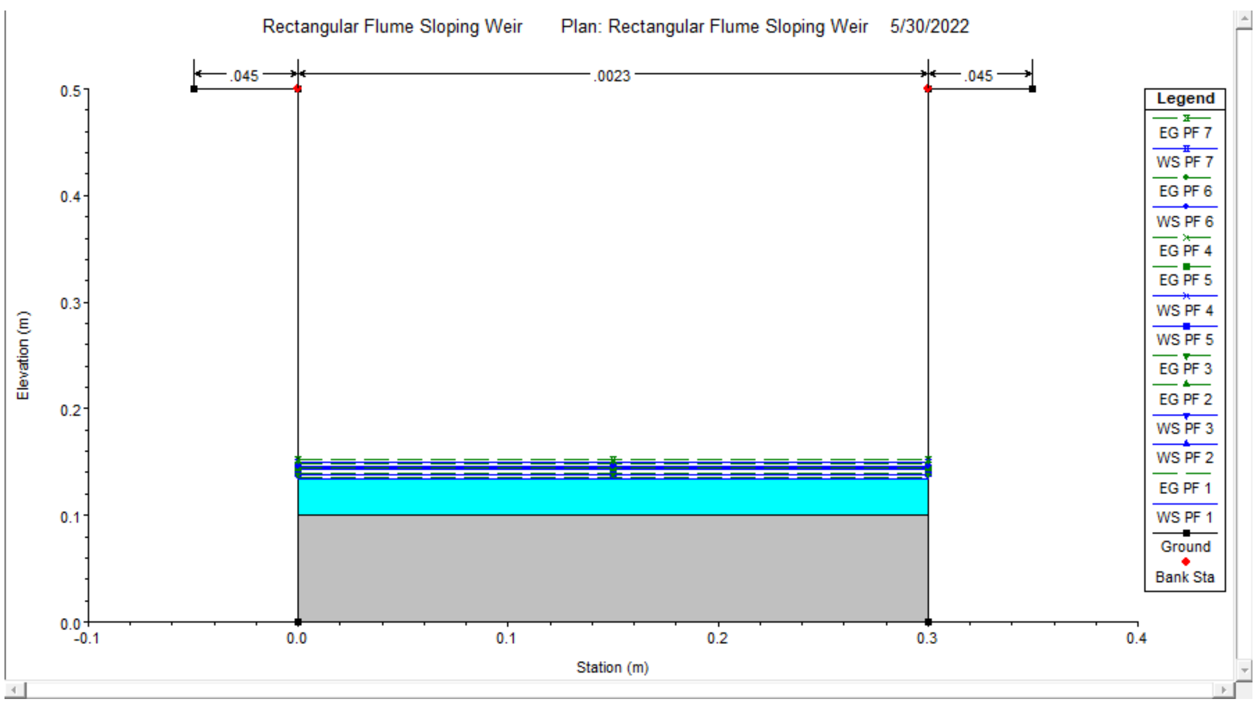


Fig 5.9 Cross Section of Inline Structure

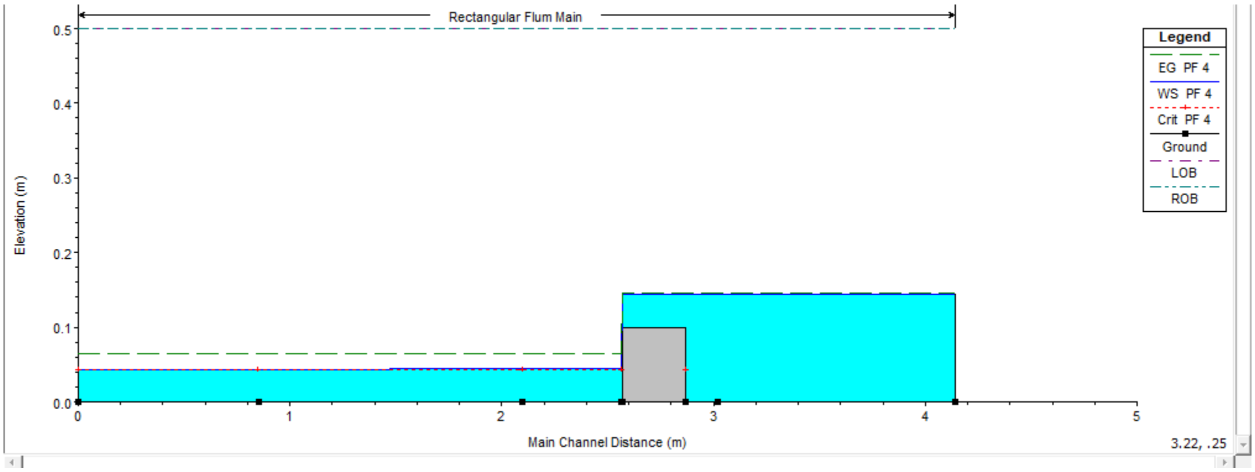


Fig 5.10 Profile Plot for Rectangular Weir (Vertical Sides)

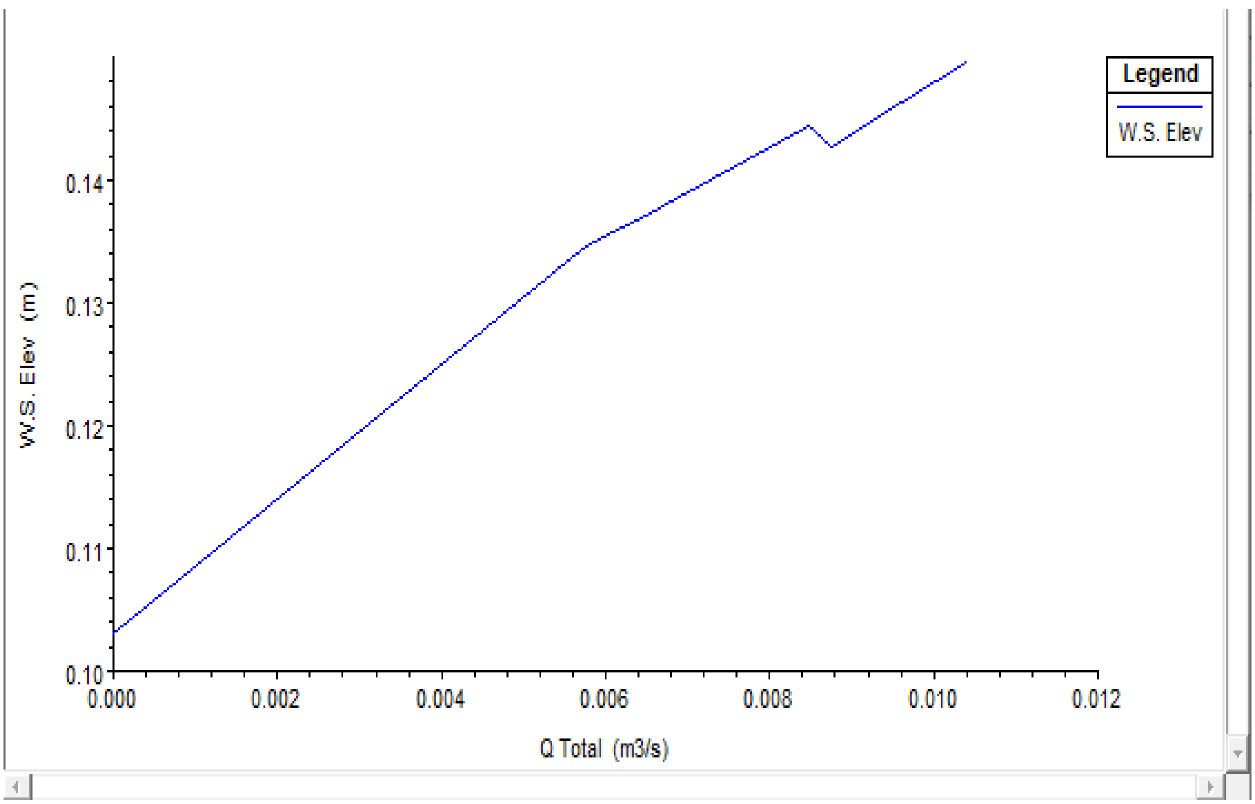


Fig 5.11 Computed Rating Curve for Rectangular Weir (Vertical Sides)

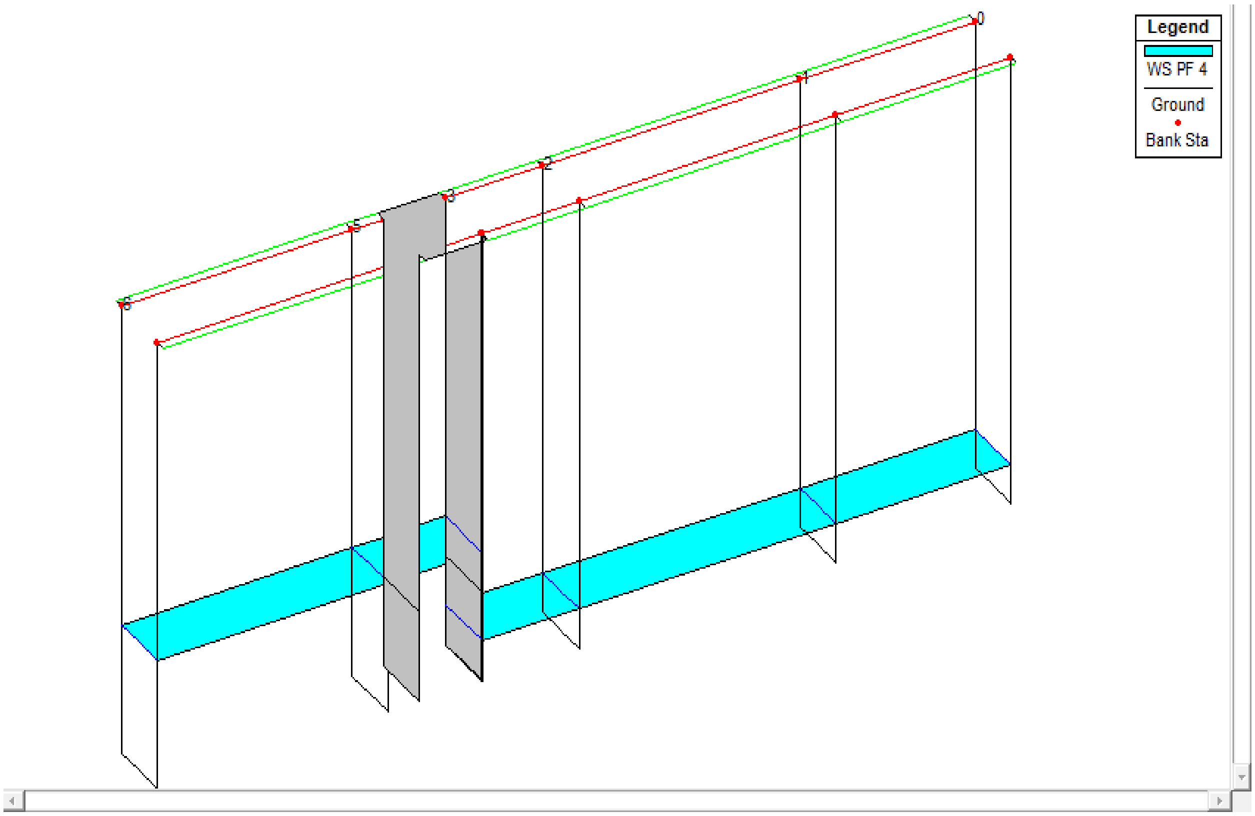


Fig 5.12 XYZ Perspective Plot for Rectangular Weir (Vertical Sides)

HEC-RAS Plan: Rectangular Weir River: Rectangular Flum Reach: Main

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Main	6	PF 1	0.0057	0.000000	0.1347		0.1357	0.000004	0.1424	0.0404	0.2999	0.1239
Main	6	PF 2	0.0067	0.000000	0.1380		0.1393	0.000005	0.1621	0.0414	0.2999	0.1394
Main	6	PF 3	0.0068	0.000000	0.1382		0.1396	0.000005	0.1638	0.0415	0.2999	0.1407
Main	6	PF 4	0.0085	0.000000	0.1444		0.1463	0.000007	0.1958	0.0433	0.2999	0.1646
Main	6	PF 5	0.0087	0.000000	0.1428		0.1449	0.000007	0.2041	0.0428	0.2999	0.1725
Main	6	PF 6	0.0096	0.000000	0.1464		0.1488	0.000008	0.2187	0.0439	0.2999	0.1825
Main	6	PF 7	0.0104	0.000000	0.1495		0.1523	0.000009	0.2319	0.0448	0.2999	0.1915

Fig 5.13 Summary of Tabular Output Results at U/S Section for Rectangular Weir (Vertical Sides)

5.1.6 Comparison of Experimental Result and Simulation Results from HEC-RAS

S.No.	W.S. Elevation of U/S Section as per Experimental Data	W.S. Elevation of U/S Section from HEC-RAS	Error %
1	0.1399	0.1347	3.860430586
2	0.1437	0.138	4.130434783
3	0.144	0.1382	4.196816208
4	0.1502	0.1444	4.016620499
5	0.1511	0.1428	5.81232493
6	0.1541	0.1464	5.259562842

Table 5.1 Comparison of Experimental Result and Simulation Results from HEC-RAS

Mean Percentage Error = 4.6 %

5.2 Approach II: Without Inline Structure

In the approach II, instead of adding an inline structure in the river reach, the cross sections at the location of the weir have been created in the Cross Section Data Entry Window under the Geometry Data. The results are displayed in the following sections:

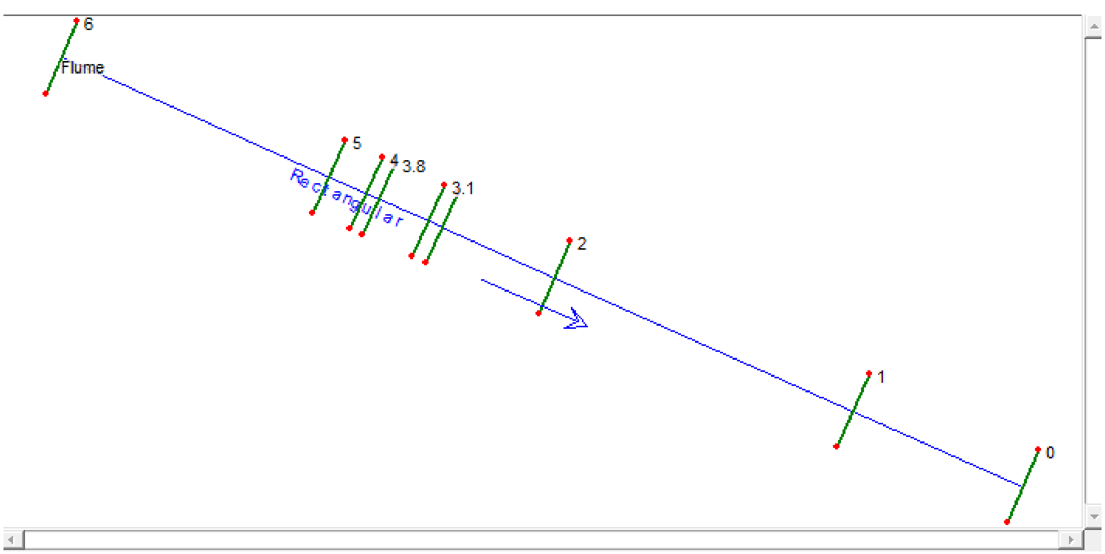


Fig 5.14 River Reach for Approach II

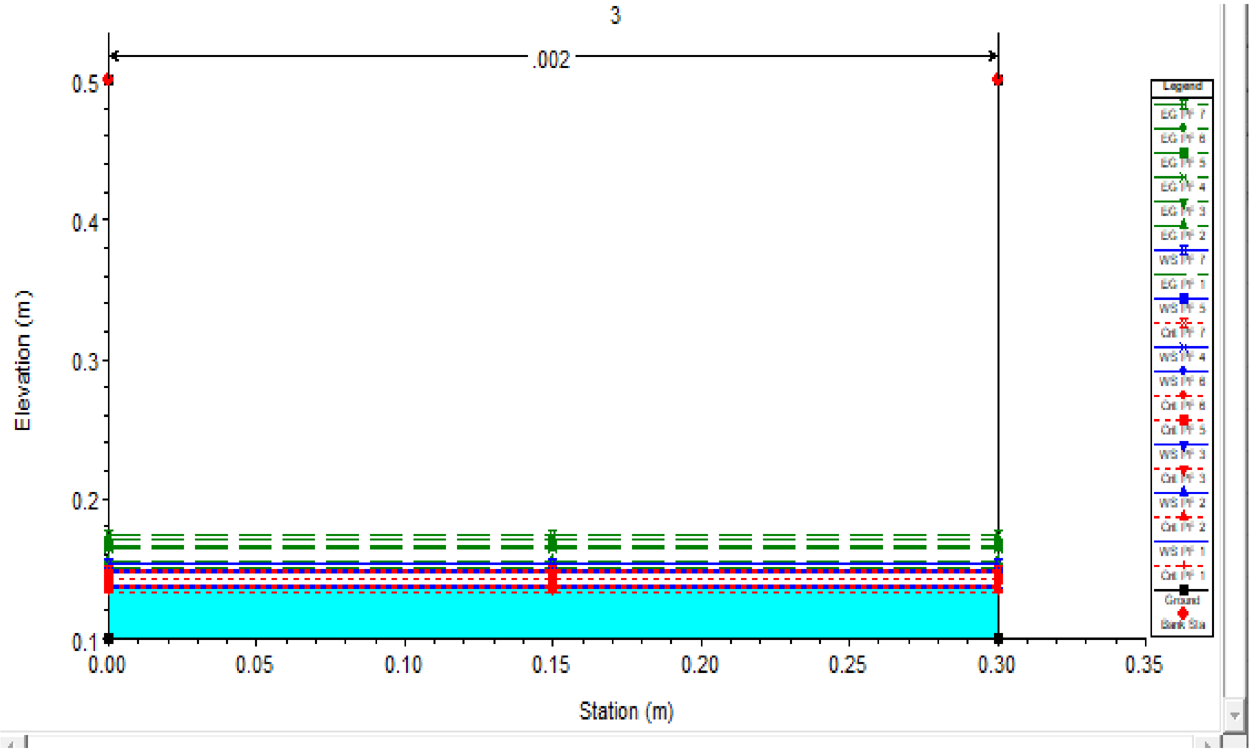


Fig 5.15 C/S at Weir Location for Approach II

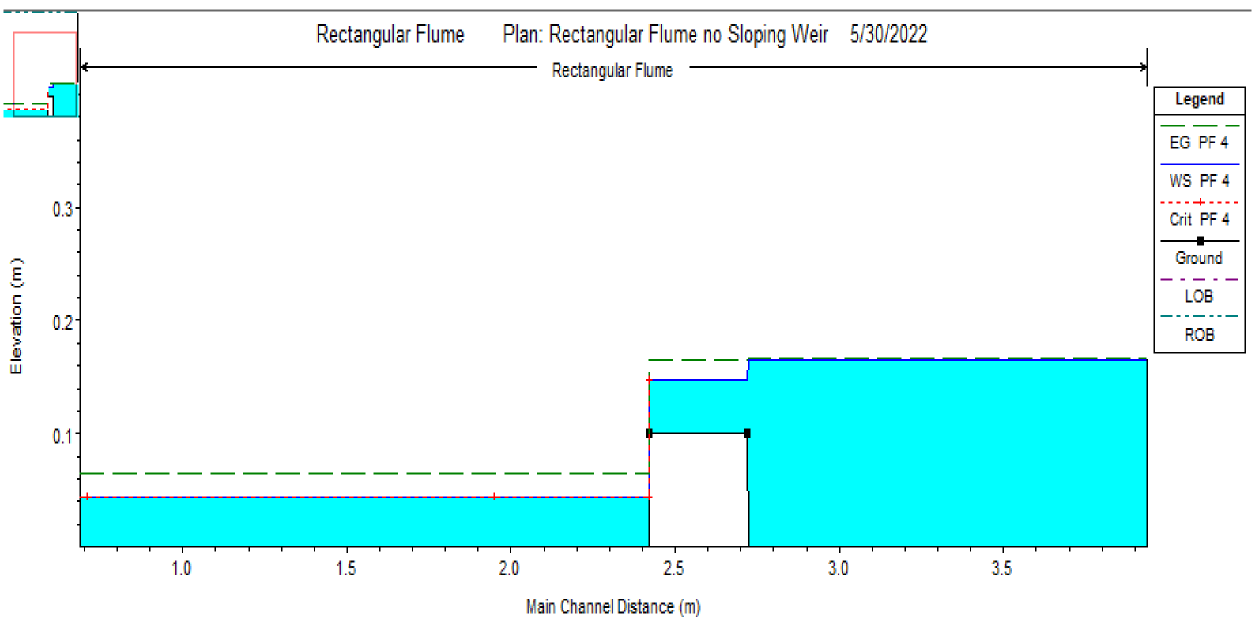


Fig 5.16 Profile Plot for Approach II

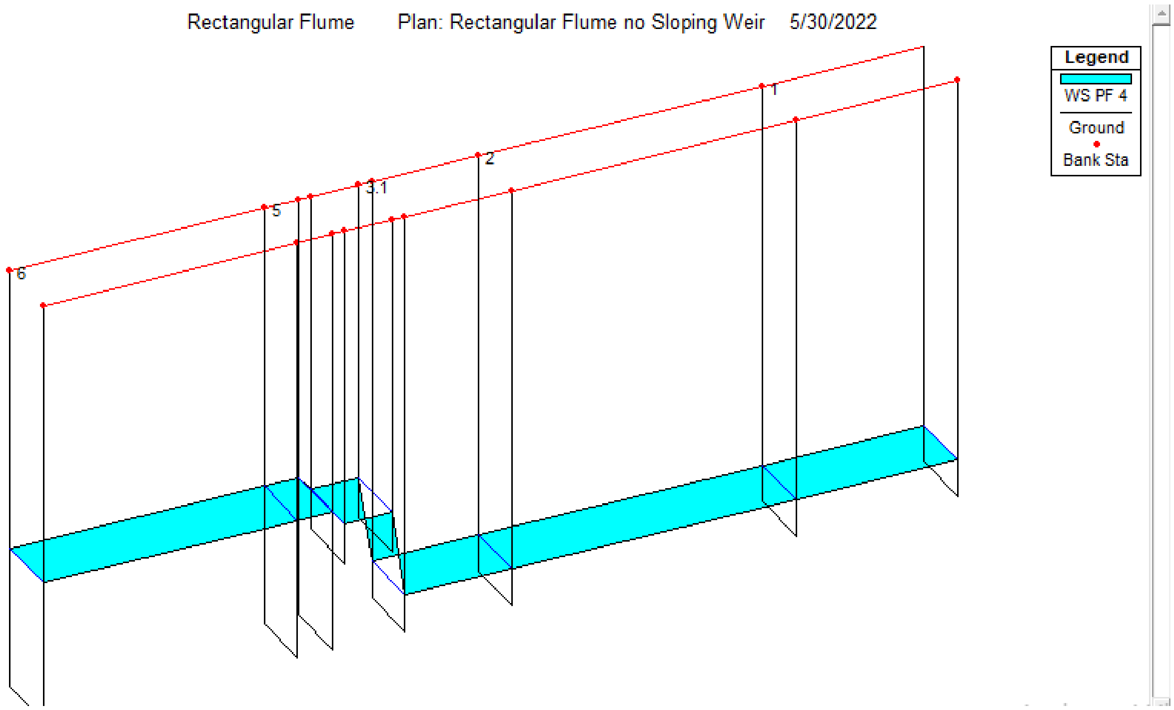


Fig 5.17 XYZ Perspective Plot for Approach II

S.No.	W.S. Elevation of U/S Section as per Experimental Data	W.S. Elevation of U/S Section from HEC-RAS	Error %
1	0.1399	0.1511	-7.412309729
2	0.1437	0.1563	-8.061420345
3	0.144	0.1567	-8.104658583
4	0.1502	0.1658	-9.408926417
5	0.1511	0.167	-9.520958084
6	0.1541	0.171	-9.883040936

Table 5.2 Comparison of Experimental Result and Simulation Results from HEC-RAS - II

Mean Percentage Error = 8.95 %

CHAPTER 6

Simulation Performed on ANSYS Fluent

6.1 Graphical Output from ANSYS Simulation

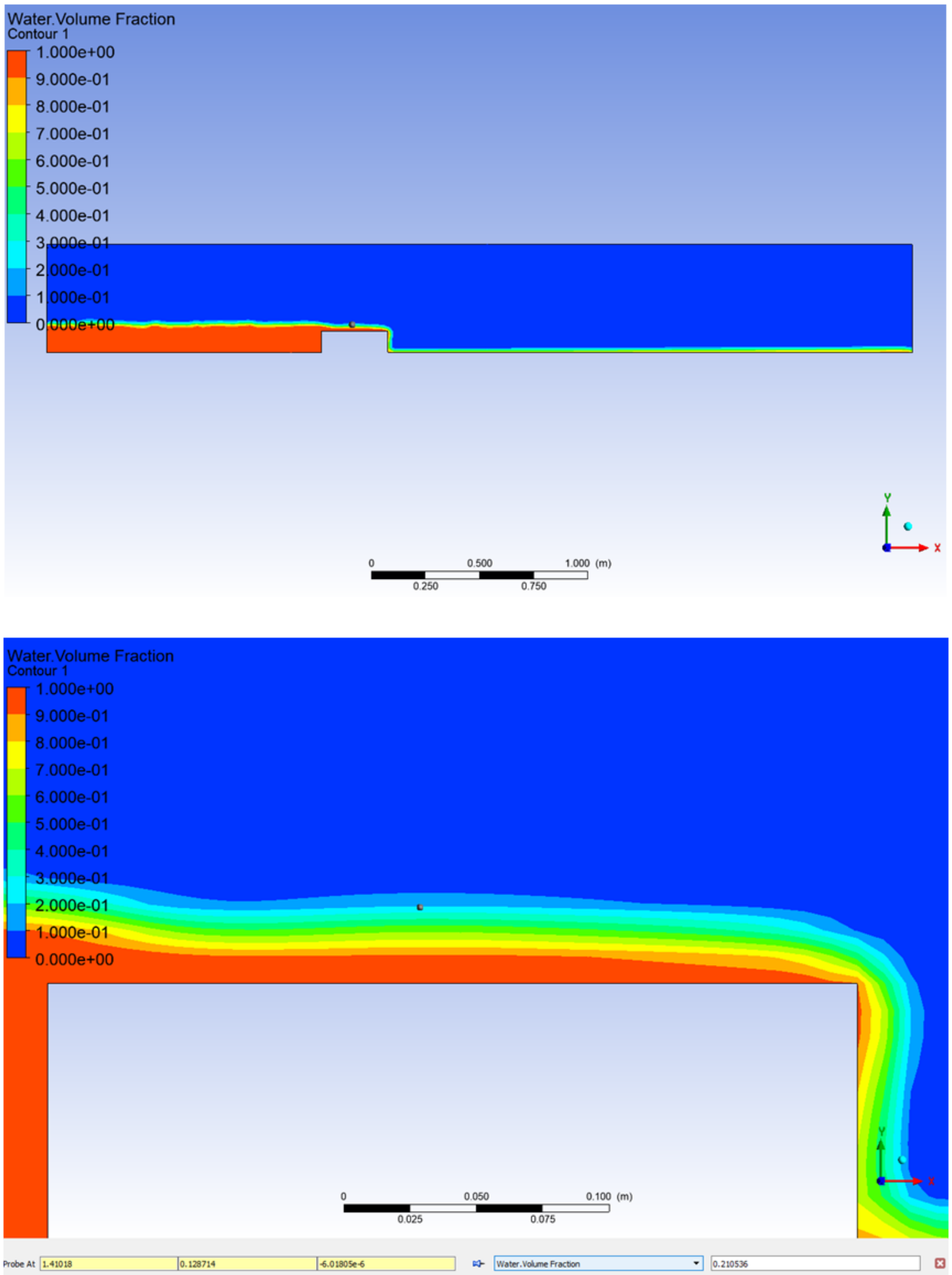
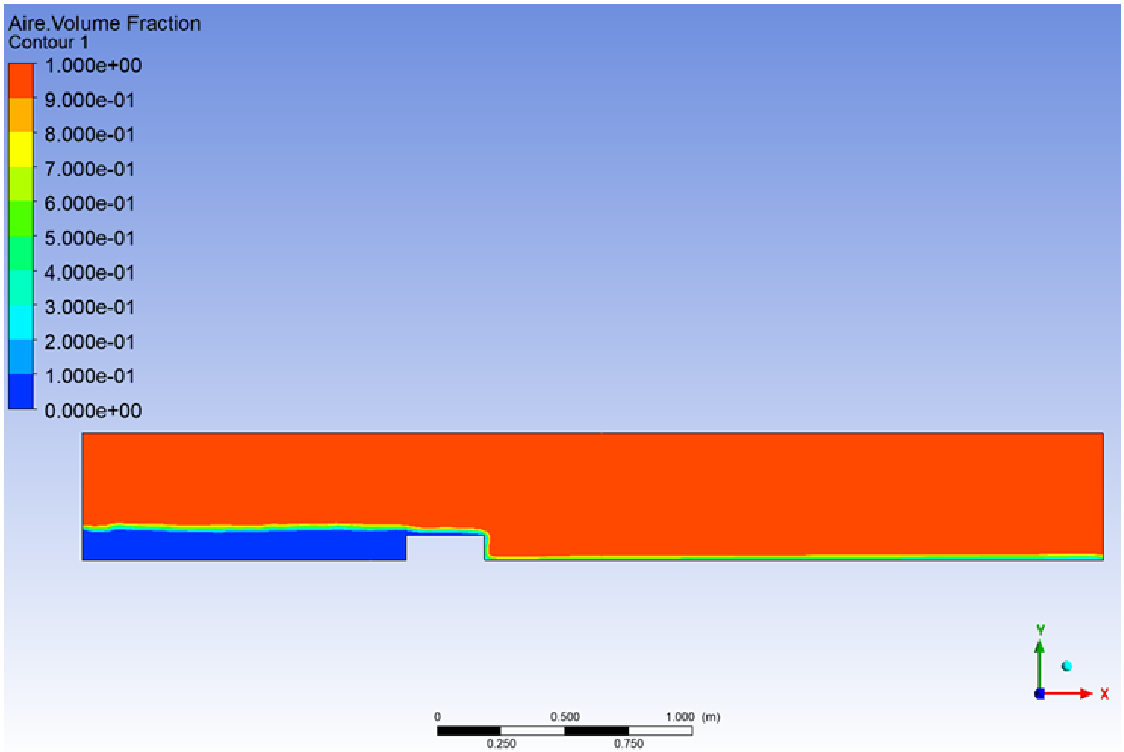


Fig 6.1 Water Volume Fraction for flow over Rectangular Weir in Horizontal Config.



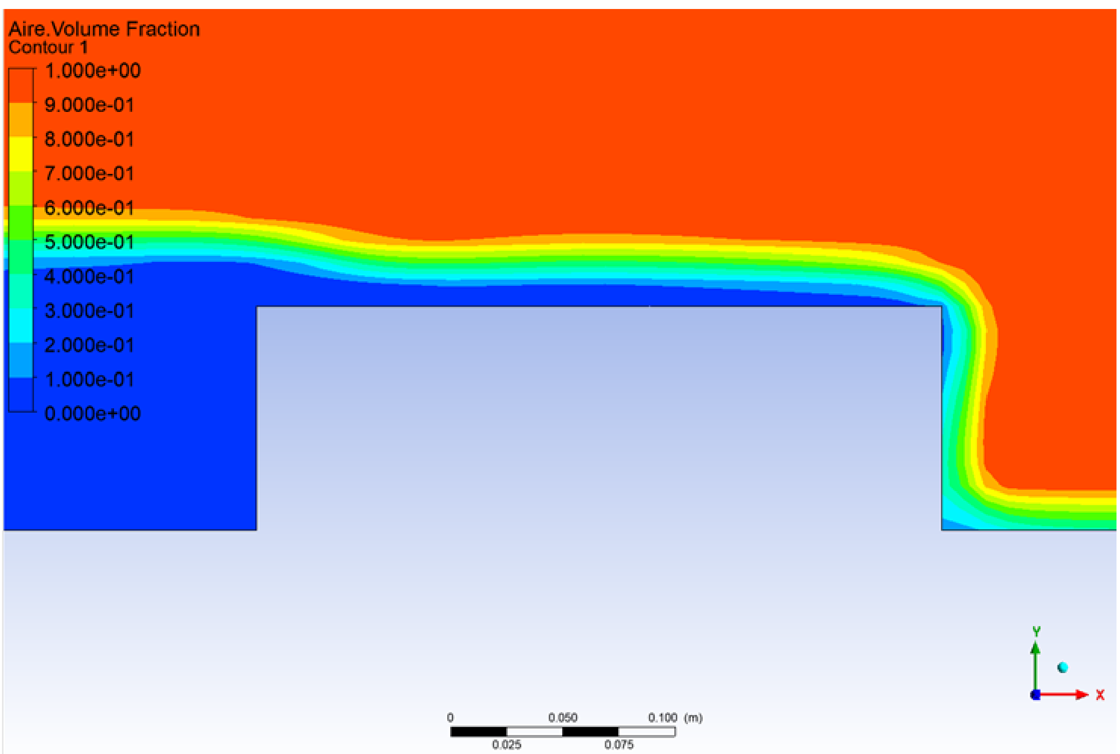


Fig 6.2 Air Volume Fraction for flow over Rectangular Weir in Horizontal Config.

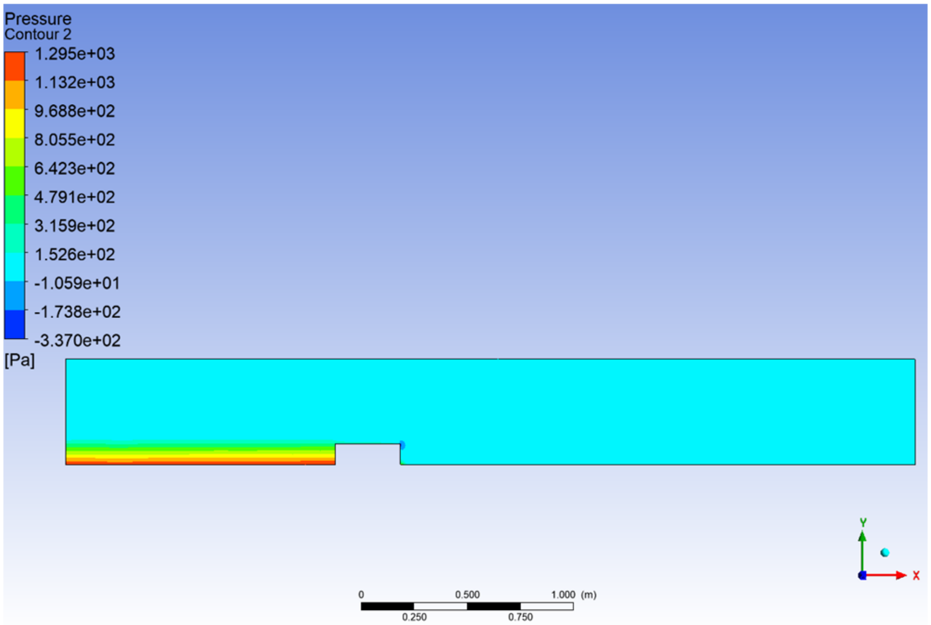


Fig 6.3 Pressure Contour for flow over Rectangular Weir in Horizontal Config.

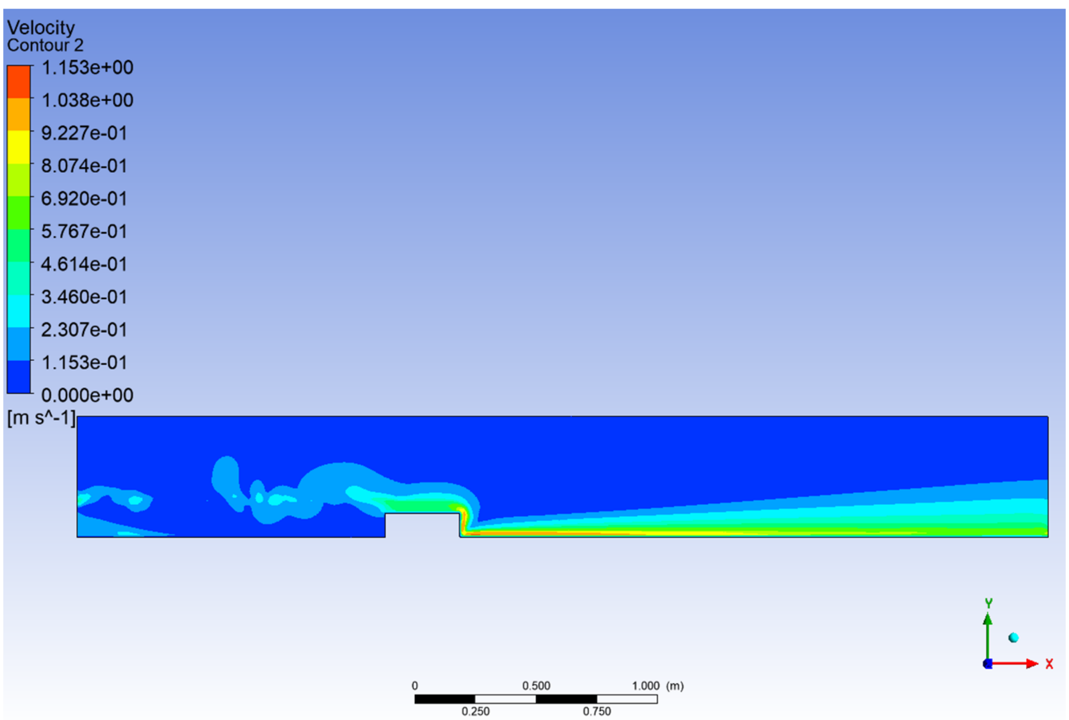


Fig 6.4 Velocity Contour for flow over Rectangular Weir in Horizontal Config.

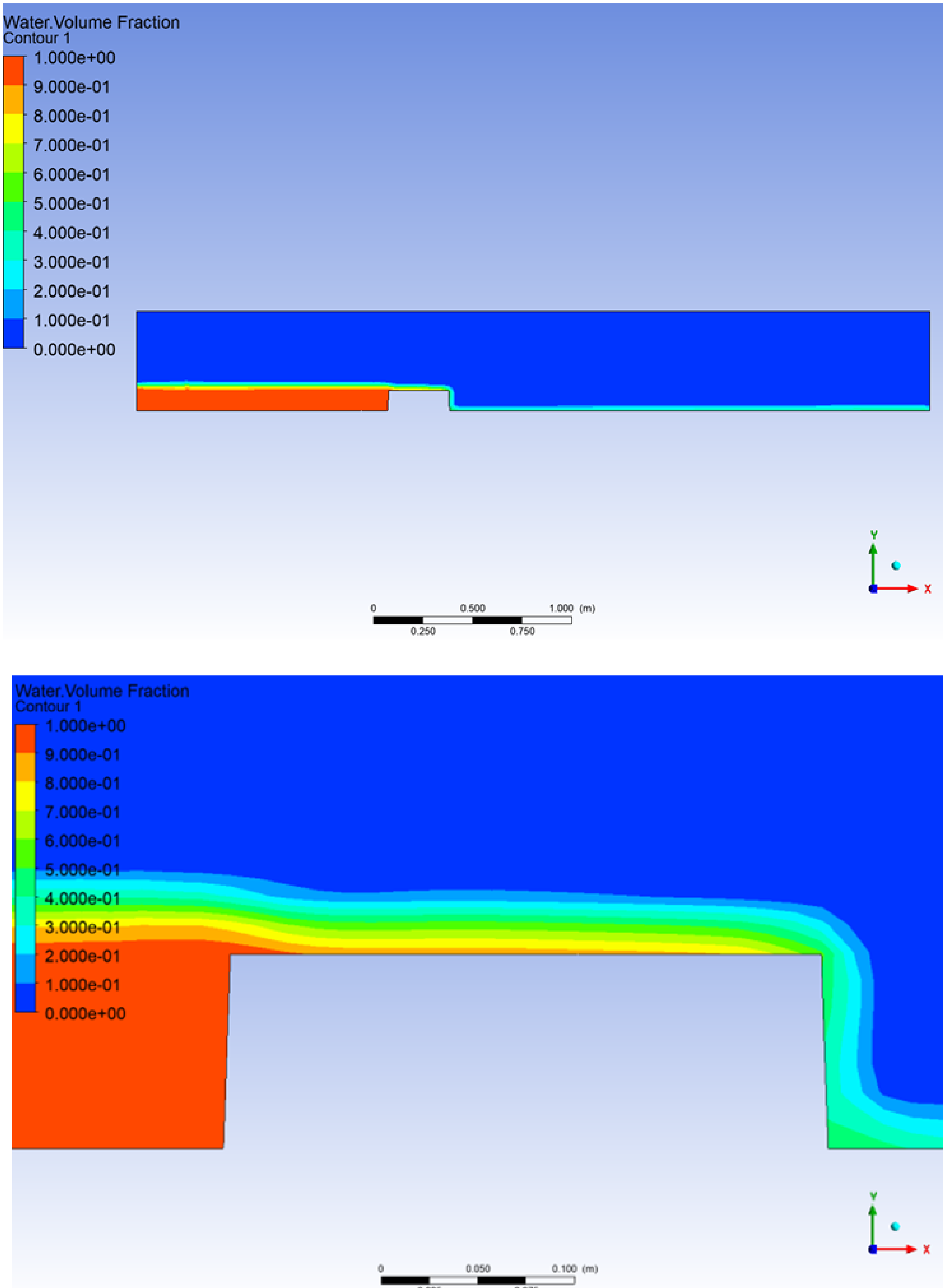


Fig 6.5 Water Volume Fraction for flow over Weir with Sloping faces

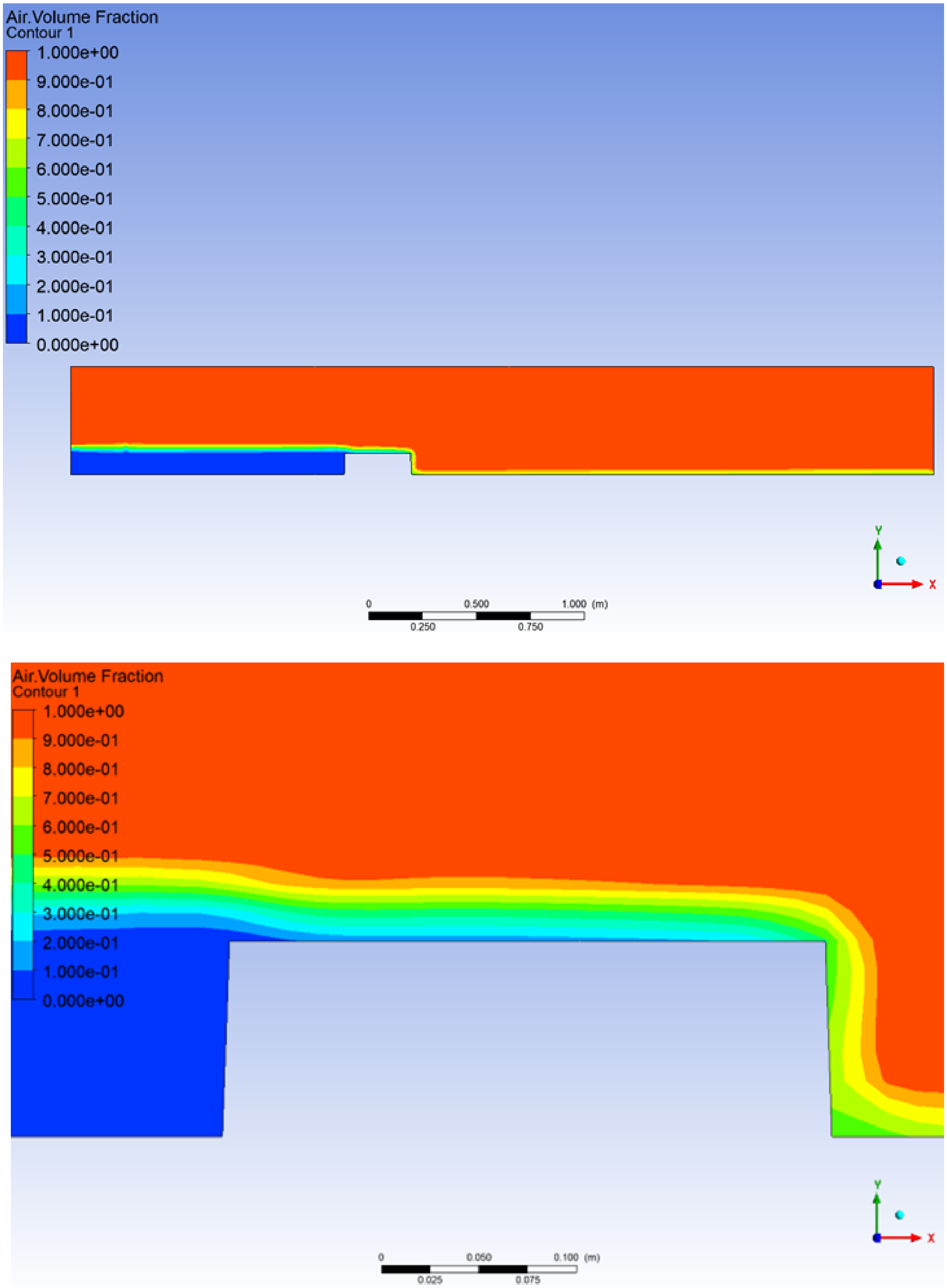


Fig 6.6 Air Volume Fraction for flow over Weir with sloping faces

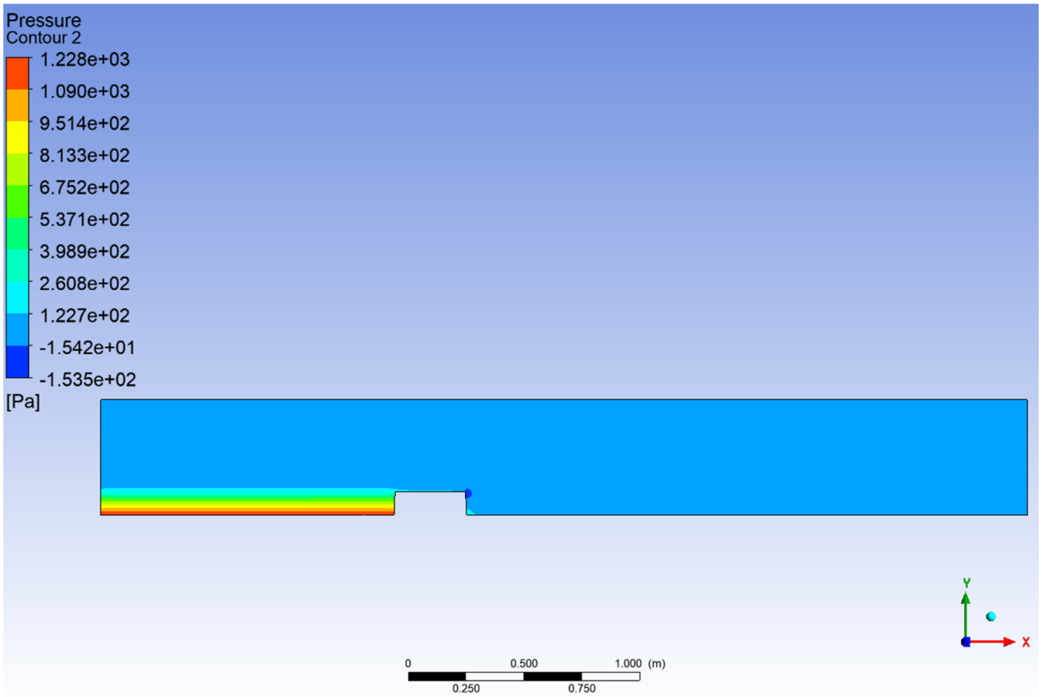


Fig 6.7 Pressure Contour for flow over Weir with sloping faces

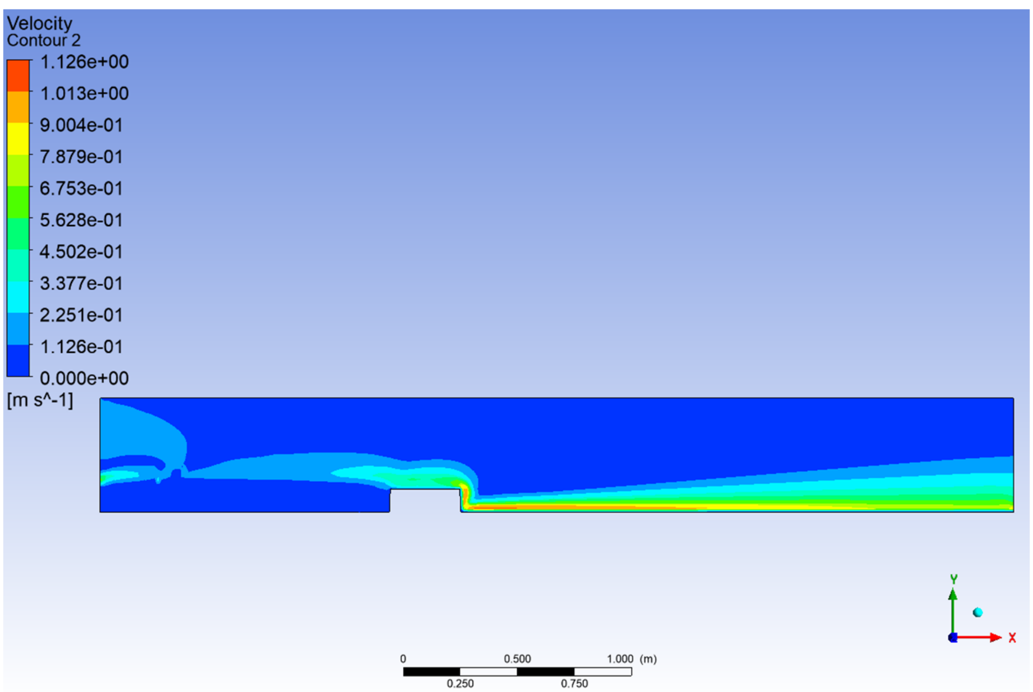


Fig 6.8 Velocity Contour for flow over Weir with sloping faces

6.2 Comparison of Experimental Results and Simulation Data Obtained via ANSYS Fluent

SNo.	U/S Height of WS Elevation above Weir Crest, H1 (m)	CFD- U/S Height of WS Elevation above Weir Crest, H1 (m)	Error % for H1	Height above crest (m)	CFD-Height above crest (m)	Error % for Height above crest
1	0.0348	0.0355	-1.97183	0.0189	0.0195	-3.07692
2	0.0386	0.0362	6.512141	0.021	0.0228	-7.89474
3	0.0389	0.0368	5.706522	0.0213	0.0246	-13.4146
4	0.0451	0.0421	7.125891	0.0242	0.0257	-5.83658
5	0.046	0.0441	4.30839	0.025	0.0264	-5.30303
6	0.049	0.0467	4.925054	0.0266	0.0272	-2.20588

Table 6.1 Comparison of Experimental & CFD Results from ANSYS Fluent for Weir in Horizontal Config.

SNo.	D/S Height above Floor of flume (m)	CFD- D/S Height above Floor of flume (m)	Error % for D/S Height	Theoretical Discharge, Q(th) (m3/s)	CFD- Theoretical Discharge, Q(th) (m3/s)	Error % for Theo. Discharge
1	0.0073	0.0068	7.828656	0.005751	0.0061	-5.72023
2	0.0098	0.0086	13.95349	0.006718	0.006914	-2.83025
3	0.01	0.0092	8.695652	0.006797	0.006946	-2.14813
4	0.0107	0.0098	9.183673	0.008485	0.008694	-2.40565
5	0.0125	0.0124	0.806452	0.00874	0.009102	-3.9803
6	0.0143	0.0132	8.333333	0.009609	0.00982	-2.14971

Table 6.1 (Contd.)

U/S Height of WS Elevation above Weir Crest	4.4344	Mean Percentage Errors
Height above crest	-6.2886	
D/S Height above Floor of flume	8.1335	
Theoretical Discharge	-3.2057	

Table 6.2 Mean Percentage Errors in Results Weir in Horizontal Config.

SNo.	U/S Height of WS Elevation above Weir Crest, H1 (m)	CFD- U/S Height of WS Elevation above Weir Crest, H1 (m)	Error % for H1	Height above crest (m)	CFD-Height above crest (m)	Error % for Height above crest
1	0.0249	0.0223	11.65919283	0.0137	0.0116	18.10344828
2	0.0298	0.0278	7.194244604	0.0174	0.0134	29.85074627
3	0.0343	0.0331	3.625377644	0.019	0.0181	4.972375691
4	0.0412	0.0402	2.487562189	0.0213	0.0194	9.793814433
5	0.0439	0.0418	5.023923445	0.0214	0.0199	7.537688442
6	0.0458	0.0421	8.788598575	0.0236	0.0219	7.762557078

Table 6.3 Comparison of Experimental & CFD Results from ANSYS Fluent for Weir kept at 2% Slope

SNo.	D/S Height above Floor of flume (m)	CFD- D/S Height above Floor of flume (m)	Error % for D/S Height	Theoretical Discharge, Q(th) (m3/s)	CFD- Theoretical Discharge, Q(th) (m3/s)	Error % for Theo. Discharge
1	0.003	0.0028	7.142857143	0.0034808	0.0032140	8.301044555
2	0.0049	0.0041	19.51219512	0.0045573	0.0043170	5.565460042
3	0.0072	0.0067	7.462686567	0.0056276	0.0053210	5.761455347
4	0.0095	0.0089	6.741573034	0.0074084	0.0073480	0.822200884 6
5	0.0114	0.0102	11.76470588	0.0081485	0.0080840	0.797549183 6
6	0.0122	0.0113	7.96460177	0.0086832	0.0082080	5.788964571

Table 6.3 (Contd.)

U/S Height of WS Elevation above Weir Crest	6.4631	Mean Percentage Errors
Height above crest (m)	13.0034	
D/S Height above Floor of flume	10.0981	
Theoretical Discharge	4.5061	

Table 6.4 Mean Percentage Errors in Results for Weir kept at 2% Slope.

CHAPTER 7

Results and Discussions

7.1 Graphical Representation of Experimental Data

The Figures 7.1 to 7.4 depict the graphs of Cd vs. H_1/L and Actual Discharge vs. Head above Weir Crest have been plotted using the data obtained from experiments.

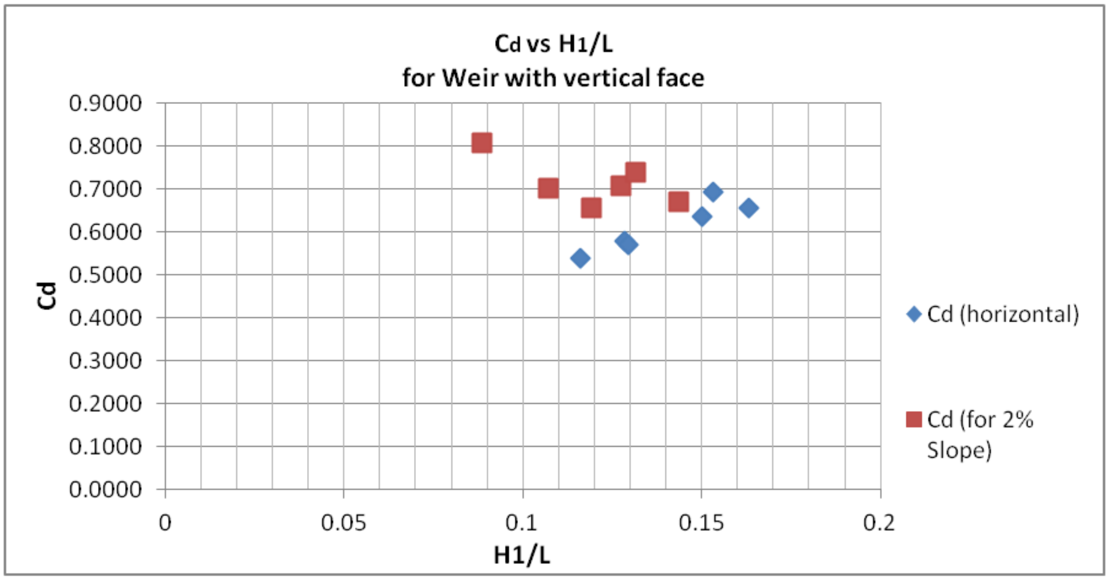


Fig 7.1 Cd vs. H1/L Plot for Weir with vertical face at horizontal config. and 2 % slope

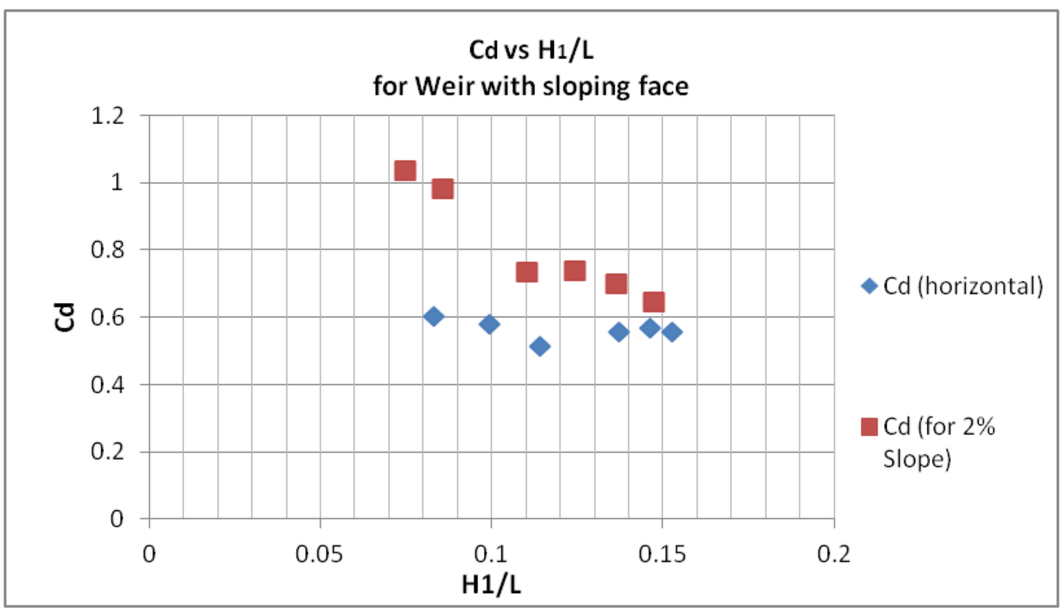


Fig 7.2 Cd vs. H1/L Plot for Weir with sloping face at horizontal config. and 2 % slope

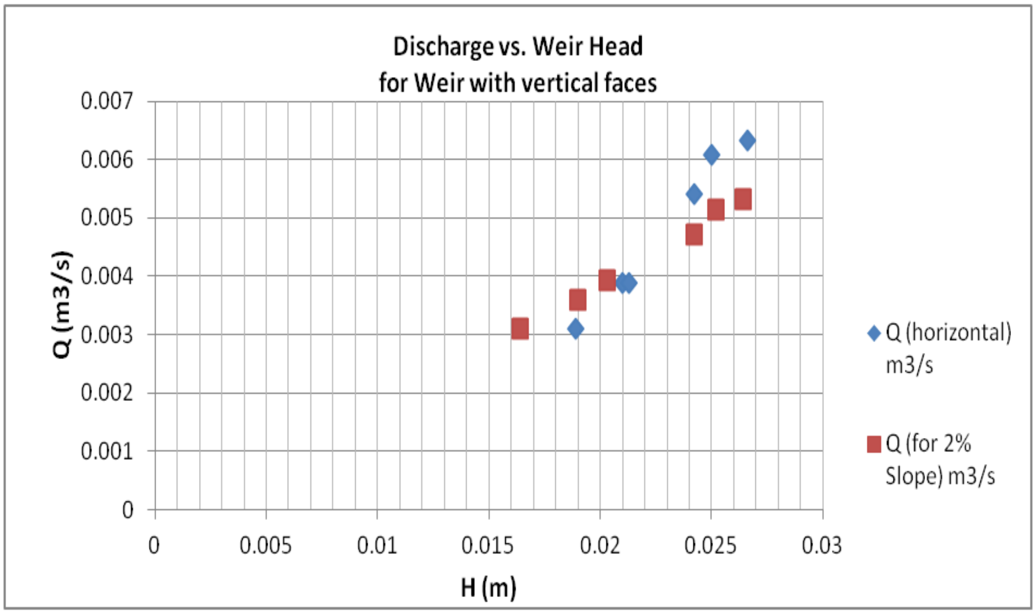


Fig 7.3 Q vs. Weir Head (H) Plot for Weir with vertical face at horizontal config. and 2 % slope

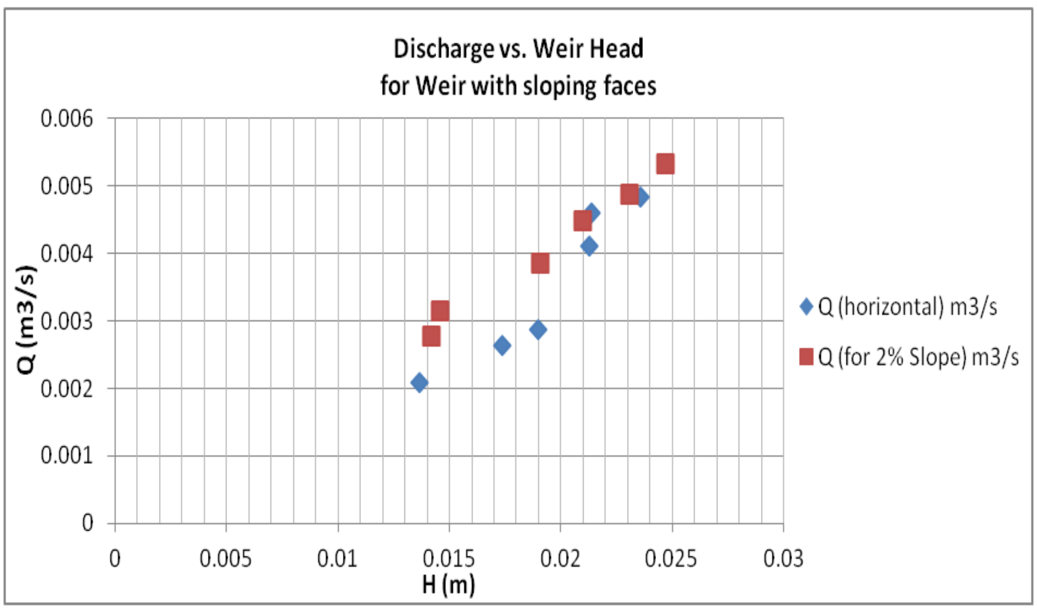


Fig 7.4 Q vs. Weir Head (H) Plot for Weir with sloping face at horizontal config. and 2 % slope

Based on the experimental data, it was observed that:

- For Weir having vertical faces, the discharge coefficient witnessed a steady increase with dimensionless ratio of H1/L, when the slope was horizontal. For a flume slope of 2%, Cd value decreased as H1/L increased. Optimum value of Cd was obtained for H1/L ratio of 0.12-0.15.

- For both configurations of flume (horizontal and sloped), the actual discharge was seen as increasing with the W.S. elevation. Naturally, the discharge values were higher for sloped config. at a given W.S. elevation.

7.2 Inferences from the HEC-RAS Simulation

The following inferences can be drawn from the HEC-RAS simulation of flow over broad-crested weirs:

- With the downstream boundary conditions set to known water surface elevation, steady, subcritical flow analysis could be performed on the broad-crested weirs, with a computing time of less than 10 seconds. With subsequent minor modifications undertaken in order to continue the iterative process, the computing time was reduced even further.

- Of the two approaches employed in the HEC-RAS Simulation, keeping the profile flow values and the d/s boundary conditions as fixed, using an inline structure in geometric data yielded a better accuracy in the prediction of W.S. elevation over the weir crest. However, the profile plots of the same were flatter and less detailed as compared to the approach that involved omitting the inline structure altogether.

- In Approach II, although the percentage error was twice relative to Approach I, and it was relatively more timely consuming to create the various cross sections across the channel reach, but the W.S. profiles so generated were more pronounced and near to the actual experimental observations in terms of the shape & location of nappe.

- For more accurate W.S. profile plots, it was inferred that point gauge readings must be taken at more locations in the channel reach.

- The XYZ perspectives plot offered an enhanced visualization capability of the entire flume arrangement, and was crucial to understand the flow behavior.

7.3 Comparison of W.S. Elevation Data from ANSYS and HEC-RAS

Both the computational softwares were capable of predicting the Water surface elevation of flow above the weir crest. Here, the error percentage from ANSYS and HEC-RAS has been compared:

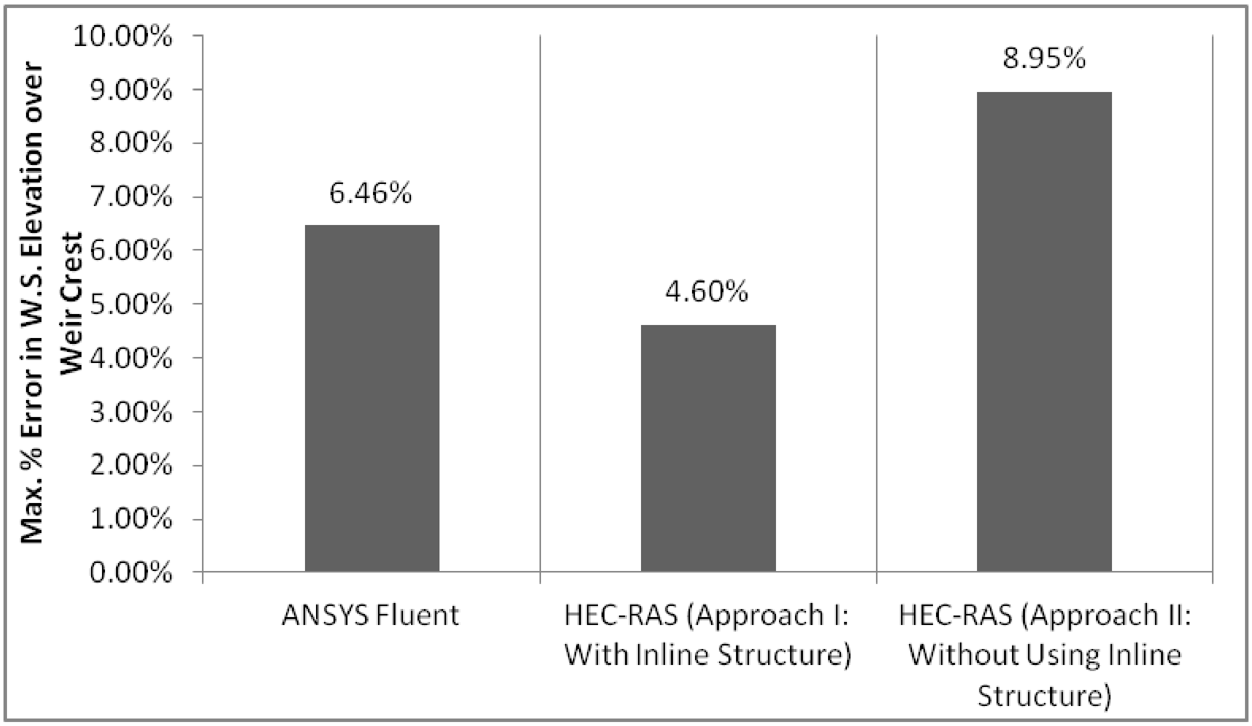


Fig 7.5 Comparison of W.S. Elevation Data from ANSYS and HEC-RAS

Conclusions

The data obtained from laboratory experiments successfully performed on two kinds of broad-crested weirs placed in a uniform, rectangular, slope-adjustable flume were verified and validated for numerous flow characteristics using two computational softwares HEC-RAS and ANSYS Fluent. Some useful conclusions that can drawn from the experimental and numerical analysis are as follows:

- Broad-crested weirs, owing to their simple geometry and large crest width proved to be useful devices to determine flow characteristics in a channel like discharge coefficient, water surface elevation, velocity profiles, boundary shear stress and so on, in a laboratory setting.

- Using standard flume arrangement equipped with the capability to measure flow parameters for multiple discharge runs as well as for longer durations is necessary for more accurate data. A higher pumping capacity of the water supply, and high-precision devices to measure actual discharge and head at various locations are needed.

- The actual discharge over the weir crest increased consistently with rise in the W.S. elevation, regardless of the flume configuration (horizontal or sloped). However, the same was not observed in the case of Cd vs. H1/L relation.

- In comparison to ANSYS Fluent, HEC-RAS software offered an ease of data input and flow simulation, while also providing a wide variety of output data. On the other hand, ANSYS Fluent, although being time consuming in model-creation and computation, gave a much more comprehensive picture of the flow over the weir in addition to a fairly less error percentage.

Future Scope of Study

Using longer length flumes and greater precision devices for measurement of flow parameters, more accurate data can be obtained for a better numerical simulation on HEC-RAS. In addition, broad-crested weirs of varying shapes, such as round-nosed, trapezoidal, single & multi-stepped etc. may be employed for analysis.

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AVNEESH_SINGH_SISODIA_MTECH_HWRE_MAJOR_PROJECT_2K20_HFE_01.pdf

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Proforma for Submission of Thesis/Dissertation

Student Name	Registration Number	Course and Branch	Title of the dissertation	Name of the Guide
AUNEESH SINGH SISODIA	2K20/HFE/01	M.TECH HYDRAULICS & WATER RESOURCE ENGG.	SIMULATION OF FLOW CHARACTERISTICS OVER A BROAD-CRESTED WEIR USING HEC-RAS SOFTWARE	DR. MUNENDRA KUMAR

Above work has been carried out by me under the supervision of DR. MUNENDRA KUMAR

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Head of Department 31/5/22
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Proforma for Submission of M.Tech. Major Project

01. Name of the Student AVNEESH SINGH SISODIA
02. Enrolment No 2K20/HFE/01
03. Year of Admission 2020
04. Programme **M.Tech.**, Branch HYDRAULICS AND WATER RESOURCE ENGG.
05. Name of Department CIVIL ENGG., DTU
06. Admission Category i.e. Full Time/ Full Time (Sponsored)/ Part Time: FULL TIME
07. Applied as Regular/ Ex-student REGULAR
08. Span Period Expired on ....
09. Extension of Span Period Granted or Not Granted (if applicable) ....
10. Title of Thesis/ Major Project Simulation of Flow Characteristics Over a Broad Crested Weir Using HEC-RAS Software.
11. Name of Supervisor DR. MUNENDRA KUMAR
12. Result Details (Enclose Copy of Mark sheets of all semesters) :

S. No.	Semester	Passing Year	Roll No.	Marks Obtained	Max. Marks	% of Marks	Details of Back Paper Cleared (if any)
01	1st	2020	2K20/HFE/01	9.71	10	97.1	
02	2nd	2021	2K20/HFE/01	9.29	10	92.9	
03	3rd	2021	2K20/HFE/01	8.67	10	86.7	
04	4th (P/T only)						
05	5th (P/T only)						

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M. Kumar.
Signature of Supervisor

31/5/22
Signature of HOD with Seal

(Instructions for filling up the Form may see on back side please.)

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S. No. 292367

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

STATEMENT OF GRADES

Master of Technology in Hydraulics & Water Resources Engineering

(Department of Civil Engineering)

Name : AVNEESH SINGH SISODIA   Roll No. : 2K20/HFE/01

Month & Year of Examination : DECEMBER , 2020   Semester : FIRST

Subject Code	Subject Title	Credits	Credits Secured	Grade
HWE501	COMPUTATIONAL HYDRAULICS	4	4	O
HWE503	ADVANCED FLUID MECHANICS	4	4	O
HWE5401	ADVANCED HYDROLOGY	4	4	O
HWE5301	WATER POWER ENGINEERING	3	3	A+
HWE5201	SEMINAR	2	2	A+
		17	17	

AB : Absent   DT : Detained

Credits Secured / Total : 17 / 17   SGPA : 9.71

Dated : Mar 10, 2021

Date of Declaration of Result Feb 11, 2021

CONTROLLER OF EXAMINATIONS

Classification of Results :

(i) Structure For Grading of Academic Performance

Academic Performance	Grades	Grade Points
Outstanding	O	10
Excellent	A+	9
Very Good	A	8
Good	B+	7
Above Average	B	6
Average	C	5
Pass	P	4
Fail	F	0
Incomplete	I	--

(ii) The Semester Grade Point Average (SGPA) shall be calculated on the basis of the credits and Grade points in the course of the semester passed by the student as follows :

$$S.G.P.A = \frac{\sum_{i=1}^{n} C_i X P_i}{\sum_{i=1}^{n} C_i}$$

(iii) The Cumulative Grade Point Average (CGPA) for the degree course :- A student having secured the minimum credits as needed for the degree course will be eligible for the award of degree. The final result will be evaluated as follows :

$$C.G.P.A = \frac{\sum_{i=1}^{m} C_i X P_i}{\sum_{i=1}^{m} C_i}$$

Where C_i credit for the course, P_i the grade points obtained for the course.

Prepared By : Gadhankar	Checked By : Manish

S. No. 307134

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

STATEMENT OF GRADES

Master of Technology in Hydraulics & Water Resources Engineering

(Department of Civil Engineering)

Name : AVNEESH SINGH SISODIA **Roll No. : 2K20/HFE/01**

Month & Year of Examination : MAY , 2021 **Semester : SECOND**

Subject Code	Subject Title	Credits	Credits Secured	Grade
HWE502	WATER RESOURCES SYSTEMS PLANNING AND MANAGEMENT	4	4	O
HWE504	ADVANCED OPEN CHANNEL HYDRAULICS	4	4	O
HWE5404	IRRIGATION AND DRAINAGE ENGINEERING	4	4	A+
GTE5304	SOIL STRUCTURE INTERACTION	3	3	A
HWE5202	GROUND WATER HYDROLOGY	2	2	A+
		17	17	

AB : Absent DT : Detained

Credits Secured / Total : 17 / 17 **SGPA : 9.29**

Dated : Nov 3, 2021

Date of Declaration of Result Jun 29, 2021

CONTROLLER OF EXAMINATIONS

Classification of Results :

(i) Structure For Grading of Academic Performance

Academic Performance	Grades	Grade Points
Outstanding	O	10
Excellent	A+	9
Very Good	A	8
Good	B+	7
Above Average	B	6
Average	C	5
Pass	P	4
Fail	F	0
Incomplete	I	--

(ii) The Semester Grade Point Average (SGPA) shall be calculated on the basis of the credits and Grade points in the course of the semester passed by the student as follows :

$$S.G.P.A = \frac{\sum_{i=1}^{n} C_i X P_i}{\sum_{i=1}^{n} C_i}$$

(iii) The Cumulative Grade Point Average (CGPA) for the degree course :- A student having secured the minimum credits as needed for the degree course will be eligible for the award of degree. The final result will be evaluated as follows :

$$C.G.P.A = \frac{\sum_{i=1}^{m} C_i X P_i}{\sum_{i=1}^{m} C_i}$$

Where C_i credit for the course, P_i the grade points obtained for the course.

Prepared By :	Checked By : Manish

S. No. 319739

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

STATEMENT OF GRADES

Master of Technology in Hydraulics & Water Resources Engineering

(Department of Civil Engineering)

Name : AVNEESH SINGH SISODIA **Roll No.** : 2K20/HFE/01

Month & Year of Examination : NOVEMBER , 2021 **Semester** : THIRD

Subject Code	Subject Title	Credits	Credits Secured	Grade
HWE601	MAJOR PROJECT I	3	3	A
HWE6201	SUBSURFACE INVESTIGATIONS	2	2	A+
GTE6303	GROUND IMPROVEMENT TECHNIQUES	3	3	O
HWE6403	ENVIRONMENTAL IMPACT ASSESSMENT	4	4	A
		12	12	

AB : Absent DT : Detained

Credits Secured / Total : 12 / 12 **SGPA** : 8.67

Dated : Mar 4, 2022

Date of Declaration of Result Jan 06, 2022

CONTROLLER OF EXAMINATIONS

Classification of Results :

(i) Structure For Grading of Academic Performance

Academic Performance	Grades	Grade Points
Outstanding	O	10
Excellent	A+	9
Very Good	A	8
Good	B+	7
Above Average	B	6
Average	C	5
Pass	P	4
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Where C_i credit for the course, P_i the grade points obtained for the course.

Prepared By :	Checked By :

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Date: 29-May-2022

e-Receipt for State Bank Collect Payment

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University Roll No

2K20/HFE/01

Name of the student

AVNEESH SINGH SISODIA

Academic Year

2020-2022

Branch Course

M.TECH. HYDRAULICS AND WATER RESOURCE ENGINEERING

Type/Name of fee

Others if any

Remarks if any

Examination Fee/Major Project Submission Fee

Mobile No. of the student

9015796273

Fee Amount

2000

Transaction charge

0.00

Total Amount (In Figures)

2,000.00

Total Amount (In Words)

Rupees Two Thousand Only

Remarks

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