Comparison of Experimental, ANSYS and CES for Boundary shear stress for gravel bed: No load conditions

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Abstract:

River engineers and scholars find it fascinating and difficult to analyze the gravel beds that are commonly seen in river beds. There are three bedload conditions for gravel beds: no load, moderate load, and strong load. Comparison pertaining to the boundary shear stress (BSS) observed in the gravel bed channelized free-flow systems are examined in this study over a fluctuating discharge along with changing water depths under no load circumstances. A flume-based experiment on free-surface channel flow was conducted using a fluvial bed composed of gravel with a grain size of D50 values of =representing no-load scenario with fixed gravel of 13.5 mm circumstances. Measurements of the gravel bed condition's velocity and BSShave been established. The waterway has a 0.25% longitudinal slope. Because of this, a case of no-load condition arises when gravel of size 13.5 mm is not transported. In this study two hydraulic software programs, CES and ANSYS FLUENT, are choose to compare the experimental study for gravel bed channels under various flow circumstances for determining layout of shear stress along the channel perimeter.

Keywords: Shear Stress, Velocity, Load, Gravel Bed, ANSYS FLUENT

Introduction:

When assessing a channel's flow carrying capacity, sediment transportation, and river erosion, boundary shear is crucial. Many researchers have looked into this for rigid and smooth channels. It is less common to see evaluation of shear stress profiles in channels exhibiting roughness discontinuities in the literature.

The research detailed in these investigations based on a number of laboratory tests that examine sediment loads in a straight channel. The observed behavior might stem from the low rate of sediment transport often too low to treat no sediment displacement from the channel bed, only a little amount of attention has been paid to analyze the extent to which sediment movement alters the friction coefficient f.

Numerous laboratory studies involved assessing boundary shear stress (τ) at specific channel locations throughout a straight segment after conducting experiments across geometrically aligned channels provided with varying structural forms and hydraulic depths. It is well known that the geometric configuration of the channel profile longitudinal shifts in the channel bed profile arrangement of roughness elements along the boundary and the secondary current structure all affect how Shear resistance along the wetted perimeter is typically characterized in open channels (OC). The usage whether point-specific or domain-averaged border the inclusion of shear stress across many hydraulic models pertaining to fluid behavior complications such as frictional losses, sediment build up, solute spreading, and vapor cavity formation illustrates the significance of comprehending BSS distributions. The bottom shear stress needs to be divided by the entire shear stress acting on the systemin order to estimate the bed load transfer in open channel flows (OCF). Correspondingly, the sidewall shear component is necessary to investigate channel movement or as a countermeasure against side bank erosion. Furthermore, laboratory flume research in flow structure, morphological resistance due to bed irregularities, and sediment transport sometimes call for a sidewall correction process. Even with advanced turbulence models, it is challenging to calculate the differential (local) and integrated (mean) shear stress accurately. Alternatively, a number of analytical, empirical, or streamlined computational techniques were created. To calculate shear stress at the local scale, along the channel walls, or averaged over the bed typically involves reliance on dividing the cross-sectional geometry of the channel into functional sub-zones where the gravitational pull on the fluid is stabilized through the action of shear force operating along the appropriate wall regions. The basic straight rectangular channel was the subject of experimental investigations in earlier publications on OC hydraulics. Leighly (1932) proposed the use of conformal mapping to represent the distribution of boundary shear stress in OCF flow seven decades ago. He emphasized that the boundary stress exerted on the bed surface should exhibit no temporal fluctuations if there are no secondary currents. The hydraulic radius separation method developed by Einstein in 1942 is still widely applied in both field and laboratory research.

Einstein predicted that the bed resistance would cause A_b to remain static along the downstream reach of the hydraulic domain after discretizing the cross-sectional profile into two distinct sections, A_b and A_w. Likewise, the resistance of the sidewalls balanced A_w. Between areas A_b and A_w, there was no friction at the intermediate position. The bed surface reduced the energy contribution from A_b in the form of potential energy while the sidewalls reduced the energy stored in the field due to elevation provided by area A_w. He did not, however, suggest a way to pinpoint the precise location of the partition line.

Using the Preston-tube technique, Knight and Sterling (2000) examined the distribution of BSS in circular conduits that were partially filled, both with and without a smooth, flat bed. The data ranged from $0.375<\tau<1.96$ to $6.5*104<\tau<3.42*105$. His research demonstrates that the Froude number and shape affect the spatial distribution of boundary-induced shear forces. The findings have been examined in terms of how shear stress in a confined region varies as a function of perimetric position and what proportion of the total shear force acts on the conduit's lateral or basal surface. It has been demonstrated that the $\%SF_W$ values closely match the empirical formula for prismatic channels developed by Knight (1981). It has been demonstrated that boundary shear stress and secondary flow are interdependent, and its consequences for sediment transport have also been investigated.

Experimental Program:

To determine the effects of BSS on different flow dynamics associated with OCF, the methodology involved conducting experiments in the laboratory designated for fluid mechanics studies in the Civil Engineering Department, under carefully monitored laboratory conditions. The current investigation uses a tilting flume with a straight, simple trapezoidal channel that is 10 m long, 0.9 m wide at the top, 0.65 m wide on the lowermost layer, and 0.125 m deep. The test reach of the tilting flume has glass sides and a metal frame. A baffle wall is installed at the inflow section of the flume, after the inlet, and before the head gate to allow for energy indulgence by lowering turbulence and creating a consistent flow along the channel portion. Head gates are essential for maintaining consistent flow because they lessen waves that may build in the water body before they cross the canal. A tail-end gate was positioned at the flume's end point to measure the bed slope. An overbridge platform was provided in the flume to aid with experimental operations. The center of the experimental flume was supported by a hinge, and a hydraulic jack system at the flume's beginning allowed it to tilt. Fig. 1 displays the experimental channel's plan view used in this investigation. Fig. 2 displays the flume's overall configuration with the experimental equipment. Table 1 shows the Geometrical parameters concerning the experimental flow channel section.

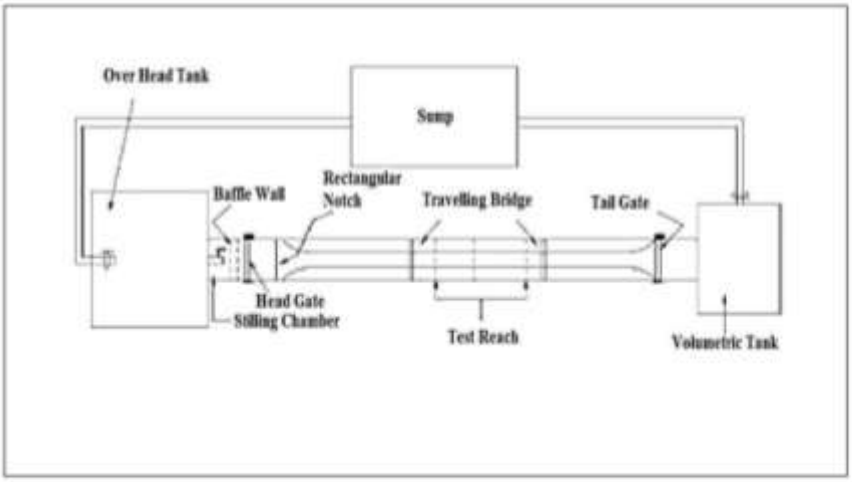

Fig. 1 Plan configuration of the experimental flow setup

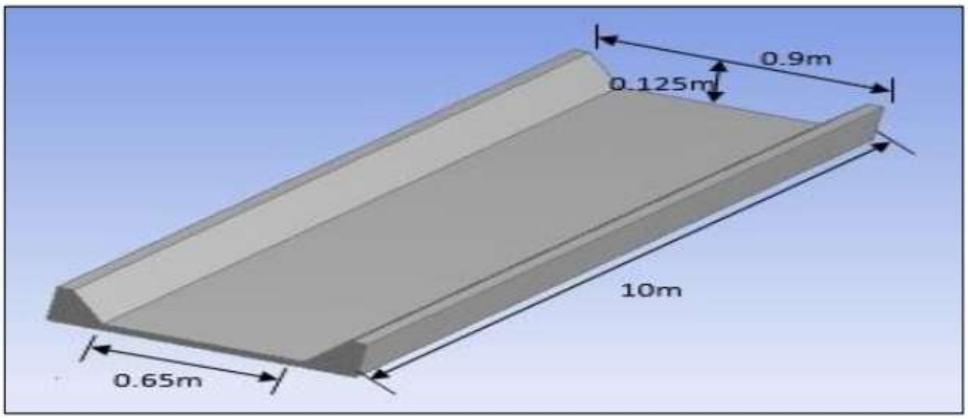

Fig. 2 Comprehensive view of the flume and associated instrumentation

Table 1 Geometrical configuration details of the experimental setup

Sl no.	Item description	Experimental channel
1	Channel type	Straight
2	Geometry of channel section	Trapezoidal
3	Channel base width (B)	0.65 m
4	Top width of channel (B)	0.9 m
5	Depth of channel (H)	0.0125 m
6	Bed slope of the channel (S)	0.25%
7	Length of whole channel	10 m
8	Test Reach Length	6 m
9	Nature of surface of bed	Rough, Gravel bed

Methodology:

The BSS are the primary parameters that will be measured in this experiment. The following is a quick description of how these parameters are measured. A point gauge that is manually controlled and fitted into the traveling bridge is used to measure the flow depth in the channel. A Micro-Pitot tube with an exterior diameter of 4.77 mm and an appropriate inclined manometer are implemented for measurement of point velocity values at multiple measurement points across the predetermined channel length. In order to move a traveling bridge across the full extent of the experimental channel, guide rails are installed in the uppermost section of the experimental flume. The traveling bridge's point gauge has the ability to move in the experimental channel's longitudinal and transverse directions. Installed on the counter side of the point gauge, the Micro-Pitot tube is secured on the bridge as well. To get the maximum deflection of the manometer reading, The Pitot tube has been spatially located and turned normal to the mainline direction. The time rise method is used to measure discharge in the channel. The experimental channel's downstream end is where the water exits, leading to a 20.866 m^2 volumetric tank. A stopwatch housed within a scaled glass tube with a minimum count of 0.01 mm is employed to monitor the variation in the water's depth over time. Toward the channel’s downstream terminus, a manually operated tailgate weir is built to control and preserve the intended flume flow depth. With the aid of a lever known as a slope altering lever, the entire structure may be adjusted to tilt the bed slope either upward or downward. Flow depth varies from 0.07m to 0.10m.

Evaluation of BSS:

Erosion is very important in hydraulic study because BSS is the acting force at a specific point exerted by a fluid flowing over a surface and functioning as the primarily involving sediment displacement. BSS in an OC can be assessed using a variety of techniques. In laboratory tests and field surveys with smooth or rough channel surfaces, the Preston tube technique and the energy gradient approach have been widely employed (Ackerman et al., 1994; Atabey, 2001;). The Preston tube approach has been applied in this investigation for gravel sizes of 13.5 mm.

Preston tube technique: This method has been utilized to calculate the BSS in the current study for the gravel size of 13.5 mm. Preston (1954) developed a method for calculating local shear (τ) in a turbulent boundary layer using a pitot (Preston) tube as the theory of an inner law pertaining to the local shear to the velocity distribution close the wall. In contact with the bottom surface, the tube is held in place. Empirically, he measured pressure differential (Δp) across wall pressure readings including static and total components determines the wall velocity distribution. This method's challenge is determining the appropriate calibration plot corresponding to the specified tube diameter. Preston (τ) proposed a dimensionless association among local shear and differential pressure (Δp) as follows:

$$\frac{\Delta p}{\rho}\frac{d^2}{v^2} = F\left[\frac{d^2\tau}{\rho\, v^2}\right]$$

Here, v denotes the fluid's kinematic viscosity, ρ represents its density, and d stands for the diameter of the Preston tube. The functional relation F is to be determined. Preston introduced a corresponding calibration equation for this purpose.

$$x^* = log_{10}\left(\frac{\Delta p d^2}{4\rho v^2}\right)$$

$$y^* = log_{10}\left(\frac{\tau\, d^2}{4\rho v^2}\right)$$

Implementation Of Hydraulic Modeling Tools for Calculating BSS:

CES – the Conveyance Estimation System:

Researchers in the context of hydraulic analysis have frequently used a three-pronged approach in the course with specific reference to channels. In addition to the analytical investigation of flow behavior in natural and engineered channel and lab-based flume experiments carried out by simulating river or environmental flows within constructed environments, a final method known as Computational Fluid Dynamics (CFD) was recently developed throughout the 1960s and is being advanced in hydraulic engineering with the rise of modern computing technologies. Therefore, CFD is essentially a numerical tool that uses a variety of techniques to solve governing equations of fluid flow expressed as differential and partial differential equations on advanced computing platforms. As a supplement to the experimental research, the current work within gravel-based straight trapezoidal sections beds has incorporated a number of numerical tool applications to the difficulties. Without altering the characteristics of the current research project, CES was utilized in this study to calculate the border shear stress.

ANSYS - FLUENT 15:

As the name implies, CFD is a technique that relies on computer-based numerical computations. It gives the engineer access to the numerical tool needed to address the problem in real time without requiring extensive experimental details or expensive equipment. Researchers have found that CFD-based simulations can drastically lower the expenses associated with experimental hydraulic models in a variety of engineering domains. By using specific boundary conditions and initial circumstances to solve a system of nonlinear equations regulating the region of concern, CFD is used to investigate the behavior of fluid flow closely. To simulate fluid flow in a straight trapezoidal channel numerically, the step has been considered.

A range of CFD applications are available that can represent multiphase flow. Some popular applications are FLUENT, a software package specifically designed for fluid flow, and ANSYS and COMSOL, that provide integrated environments for multiphysics simulation. Because it can provide findings for problems without experimental data or statistical tools (such correlations), as well as for real-time scenarios, CFD is a widely used technique for resolving transport phenomena.

Using a CFD modeling program called FLUENT, the current work attempts to study the BSS distribution over various depths of a basic trapezoidal channel with sedimentation as the unloaded state.

Results and Analysis:

Comparison of BSS distribution results for unload condition Using a Preston tube featuring a diameter of 4.77 mm and a variety of longitudinal distances, the BSS was measured at discrete intervals along the wetted perimeter. The experimental channel's BSS distribution was examined at five different flow depths. To date, shear stress has been evaluated solely for the gravel-lined bed without any load in this section boundary. Figs. 3.a to 3.e show the measured point BSSes (τ) displayed over the extent of the flow under no applied load scenario. These figures indicate that the contact between the trapezoidal channel's side wall and channel bed experiences the greatest boundary shear in both experimental

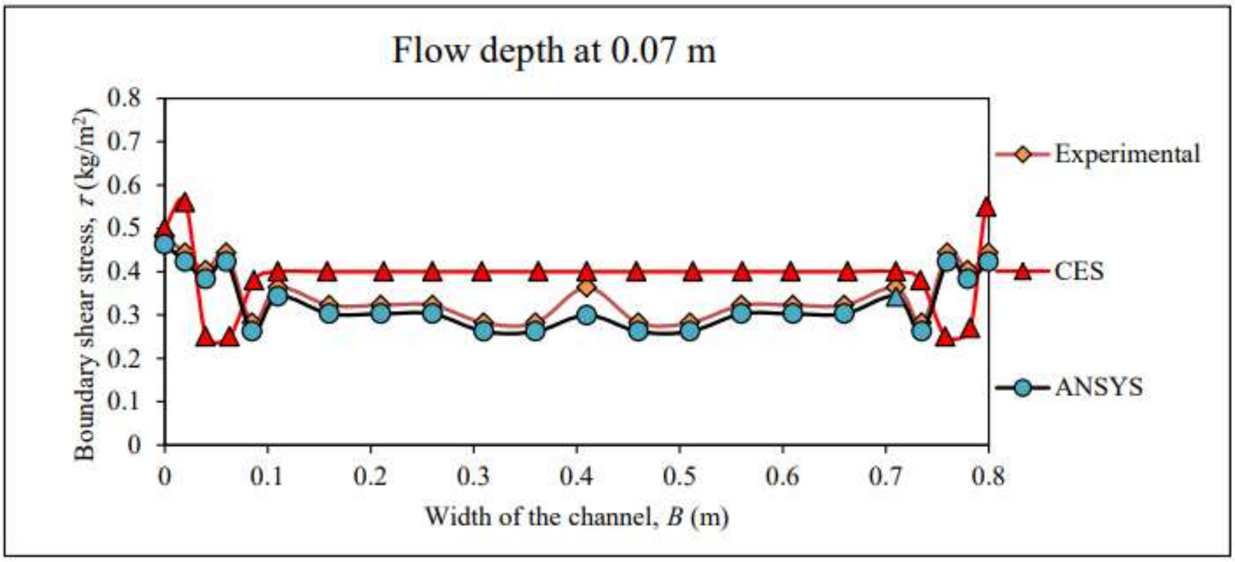

Fig. 3.a. Comparison of Boundary shear stress distribution for flow depth 0.07m

and numerical data. The BSS tends to decrease with increasing roughness, i.e., a bigger gravel bed size of 13.5 mm. The BSS at the middle along the channel rises as the flow depth increases, while the BSS at both ends tends to be the invariant across varying flow depths. When compared to experimental results, all of the numerical software produced good results. But because ANSYS can capture the 3D aspect of flow that happens inside a gravel-surfaced rough channel, unlike that, CES is unable to, ANSYS was shown to produce more accurate results than CES. CES is a type of software that exclusively produces 1D effects. It is predicated on the RANS equation's depth average. The roughness value and initial and boundary conditions for the software are identical to those found in the experimental data. The BSS distribution of experimental dataset corresponding to a gravel bed with 13.5 mm particle size is compared with CES and ANSYS data in Figures 3a to 3e. We see from these figures that ANSYS underpredicts the experimental data whereas CES overpredicts the boundary shear. Therefore, we may say that ANSYS outperformed CES in terms of BSS distribution.

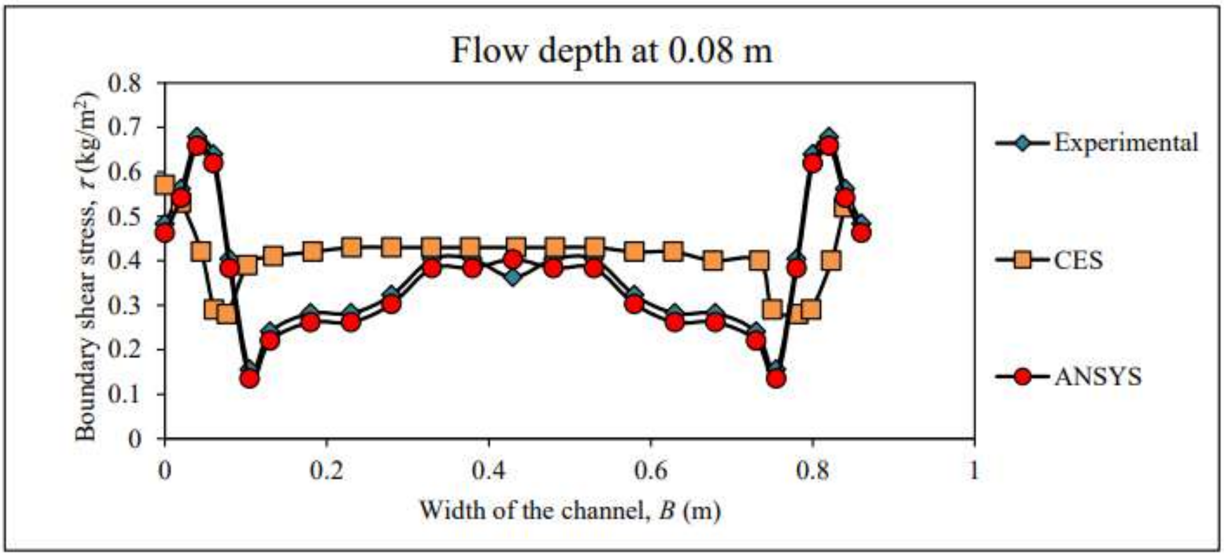

Fig. 3.b. Comparison of Boundary shear stress distribution for flow depth 0.08m

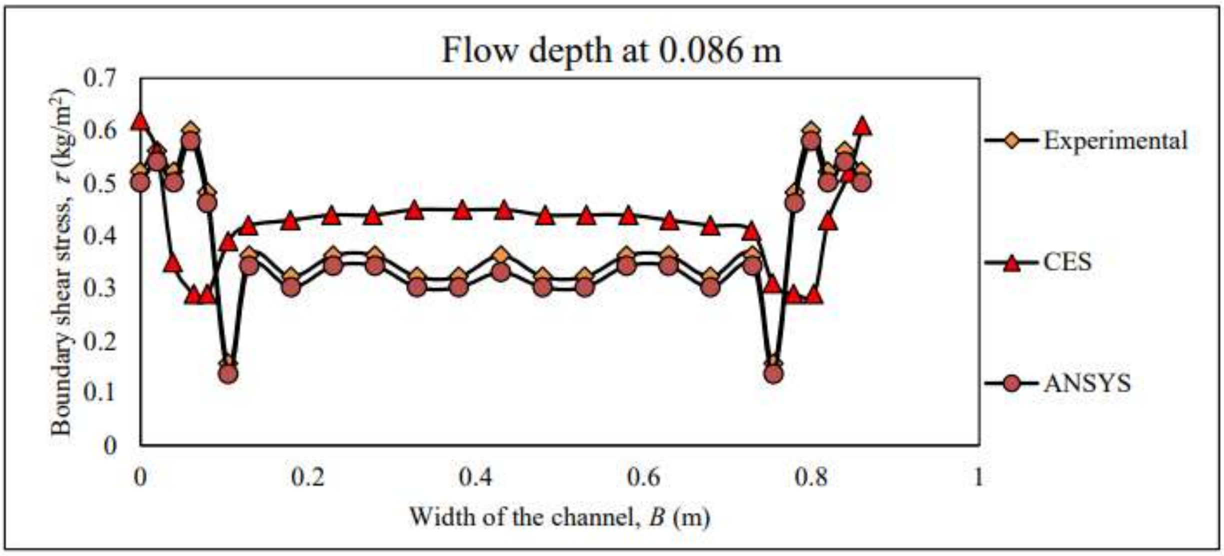

Fig. 3.c. Comparison of Boundary shear stress distribution for flow depth 0.086m

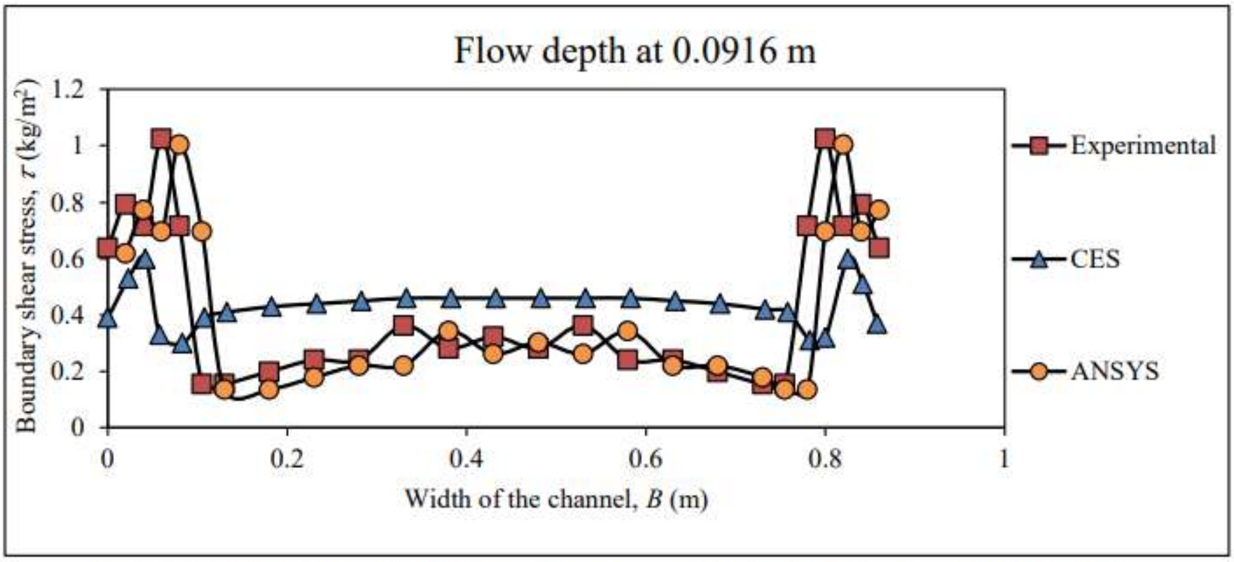

Fig. 3.d. Comparison of Boundary shear stress distribution for flow depth 0.096m

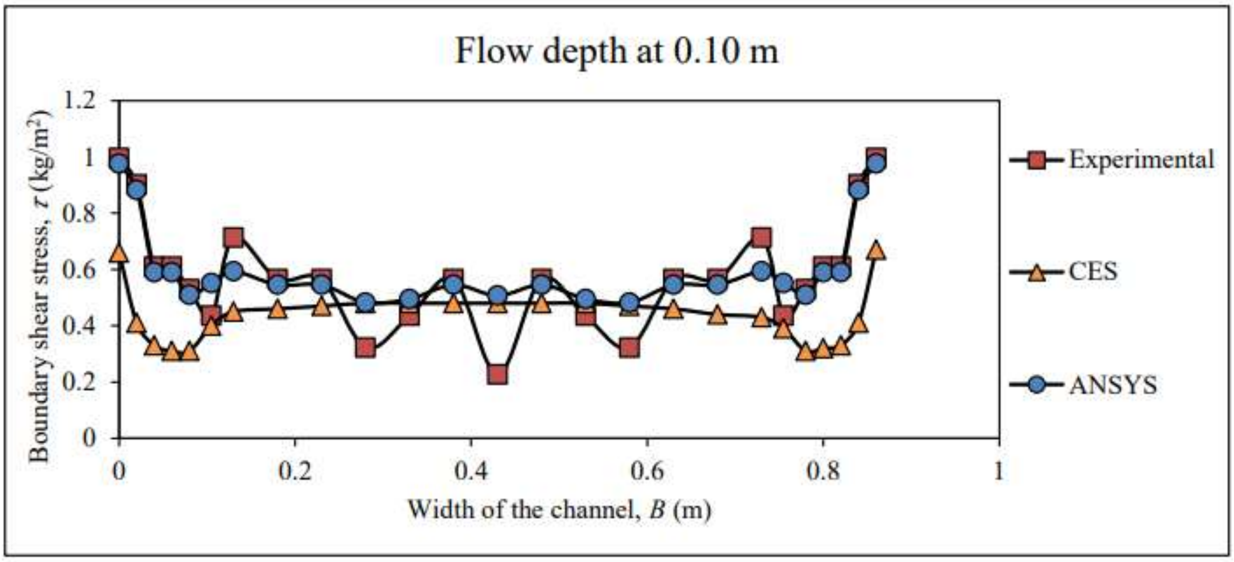

Fig. 3.e. Comparison of Boundary shear stress distribution for flow depth 0.10 m

Conclusions:

At the Fluid Mechanics Laboratory, experiments were started in gravel bed OC within an adjustable-incline flume under no load conditions at a range of flow depths. For the purposes of this study, just one kind of sediment size is taken into consideration. The current study yielded the important findings listed below. Under no load conditions, it is discovered that localized velocity at the top interface increases as the fluid depth grows. ANSYS-FLUENT projected superior results than CES used for the full range of flow depths, despite the fact that the BSS is uniformly distributed throughout the channel bed. Results from Ansys are as similar as the experimental data as compared to CES may be because of mess size. As for Ansys mess sizes are as big that it is giving accurate results. So, it is concluded that if Ansys are being used instead of experiment data can be easily obtained but CES is not that much recommended.

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