HIGHER ORDER STATISTICS OF REYNOLDS SHEAR STRESS IN NONUNIFORM SAND BED CHANNEL

Presented By:

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Introduction (Non-uniform sediment)

- ✓ Riverbeds are usually comprised of non-uniform sediment mixtures and the respective particle size distribution of sediment in transport is generally finer than the distribution of bed material because of selective transport (Wu et al.,2004).

- ✓ Most of the early experiments on sediment transport were confined to the homogeneous sediment mixture (Wilcock 1993; Zyserman and Fredsøe, 1994)

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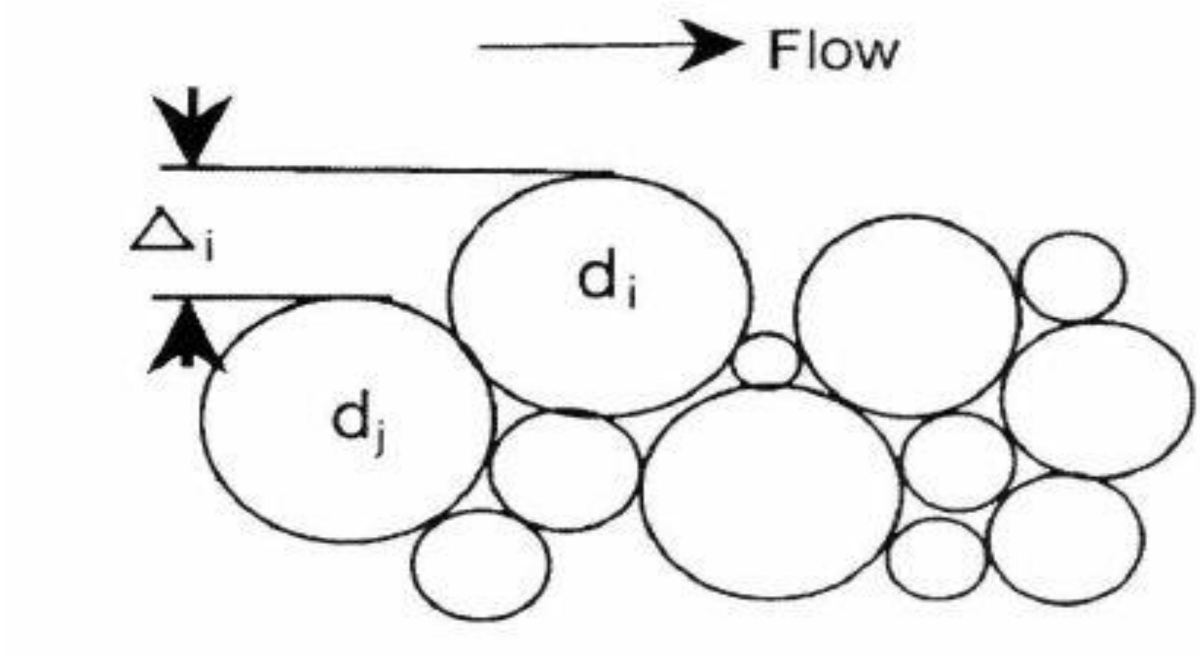
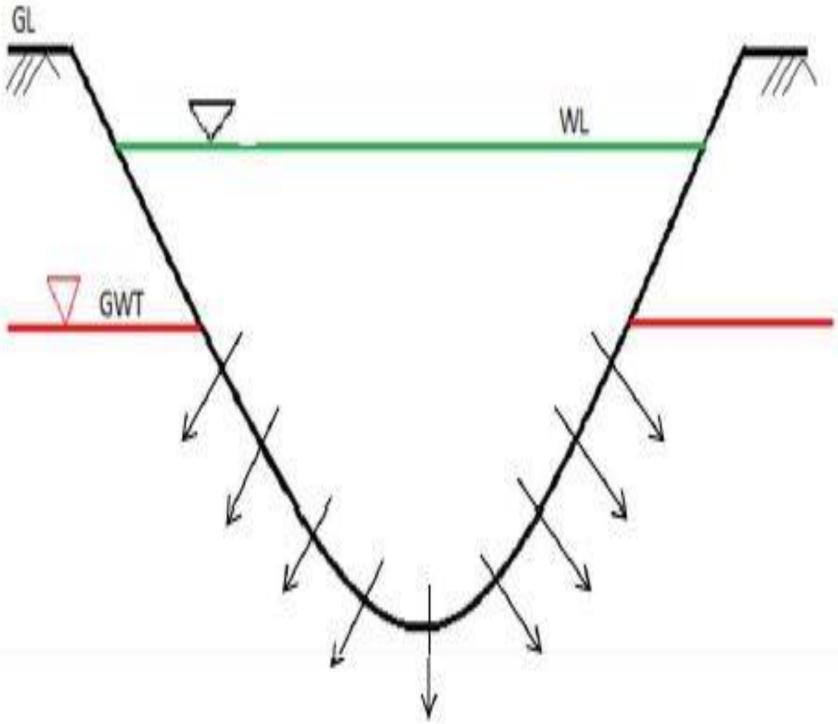
- ✓Most of the studies on the non- uniform sediment transport are based on introducing correction factors to understand the hiding and exposure effect and use these factors to modify the existing formula for uniform sediment transport (Parker *et al.* 1982; Andrews, 1983).

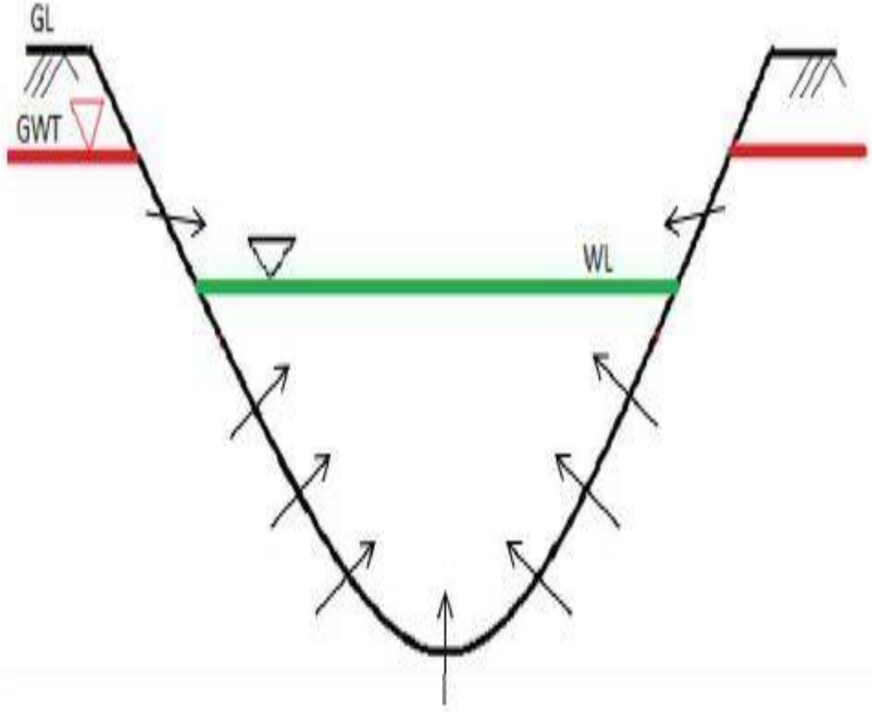


Introduction (Seepage)

Downward Seepage



Upward Seepage



Why downward seepage?

- In the present day scenario, ground water table is depleting because of the excessive use of tube-wells. Therefore, the level of ground water table is lower than the flow level in the channel, water seeps in the downward direction causing downward seepage.

Literatures (Downward Seepage)

- Downward seepage influence the main stream flow characteristics in the wall shear layer as well as the outer-flow layer (Devi *et al*., 2016).

- Devi *et al.* (2016) observed that downward seepage increased stream wise velocity near the bed resulting in the formation of a more uniform velocity distribution.

- Increment of bed shear stress with downward seepage causes increased sediment transport (Sreenivasulu *et al*., 2011)

Motivation of Present Study

- Although many studies have investigated flow hydrodynamics or turbulent characteristics with seepage in case of uniform sand, the flow characteristics over non-uniform sand bed channel with downward seepage remain unexplored.

- The previous studies is mainly deals with the small seepage zone length as compared to channel length.

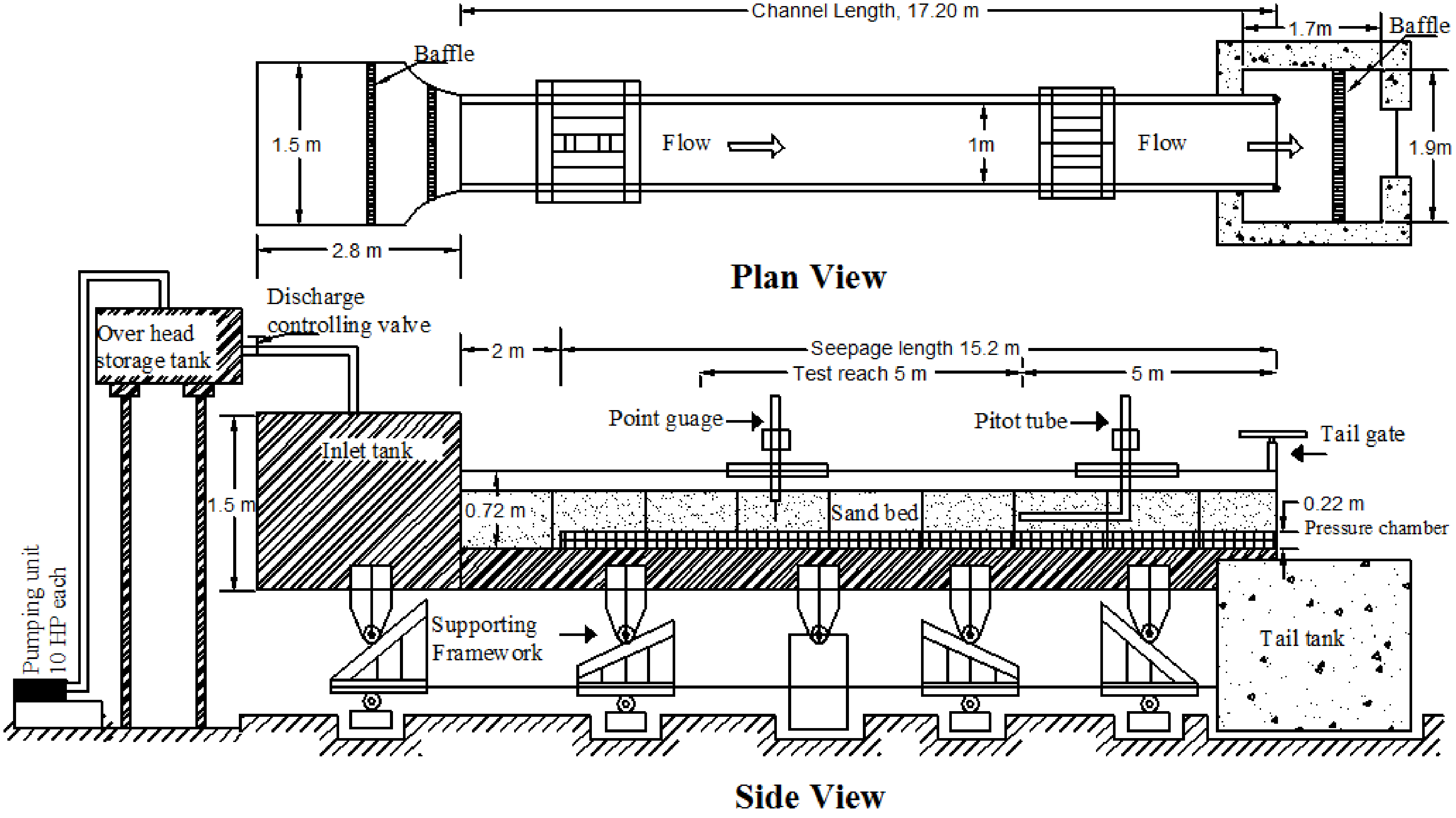
The sediment transport rate increases with seepage zone length (Cao and Chiew, 2014).

Objectives

- Considering the importance of seepage zone length and non uniform sediment, the present study aims to investigate the effect of downward seepage flow on the turbulent flow characteristics over a mobile rough boundary.

- The experimental result will deliver important information related to the turbulence characteristics, such as velocity, Reynolds shear stress and conditional Reynolds shear stresses.

Experimental set-up and methodology


Plan View

Side View

Contd…

- Water surface slope and flow depth have been measured with the help of pitot tube and digital point gauge
- Main channel discharge was measured with the help of rectangular notch.

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- Seepage discharge is controlled by valves connected to electromagnetic flow meter.

Experimental technique and measurement

- In the no seepage (NS) run, Water is introduced to the channel by gradually opening a valve located at the overhead tank till required discharge Q and corresponding flow depth y are registered.

- Consequently after conducting the experiment with no seepage, different downward seepage discharge of 10% and 15% of the main flow discharge were applied by controlling the electro-magnetic flow meters installed at the downstream section of the flume.

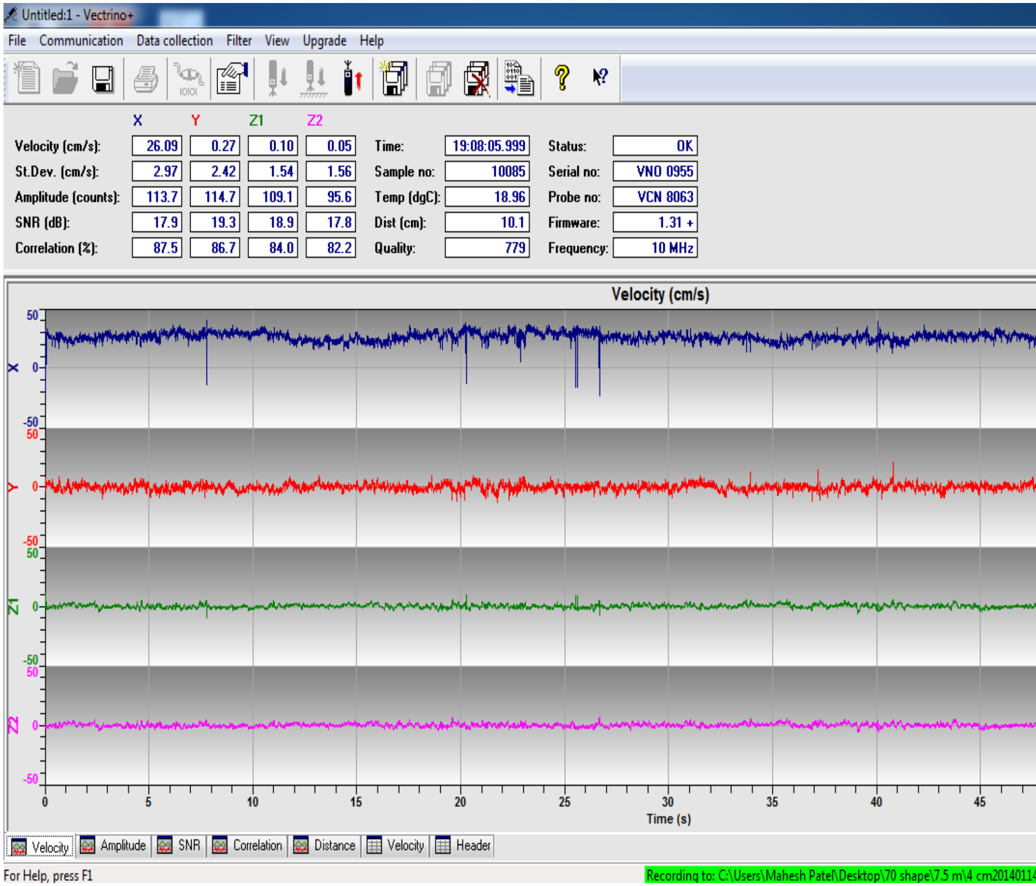
Data Collection

- Data was collected at the center line of the channel cross section at a distance of 8m from the downstream end of the flume.

Median grain size, d_{50} (mm)	Discharge, Q (m^3/sec)	Depth of flow, y (m)	Kramers coefficient, M	Bed Slope, S_0
0.50	0.0402	0.112	0.16	0.001

Contd…

- Velocity measurements were taken with the help of Vectrino+ Acoustic Doppler Velocimeter (ADV) developed by Nortek.

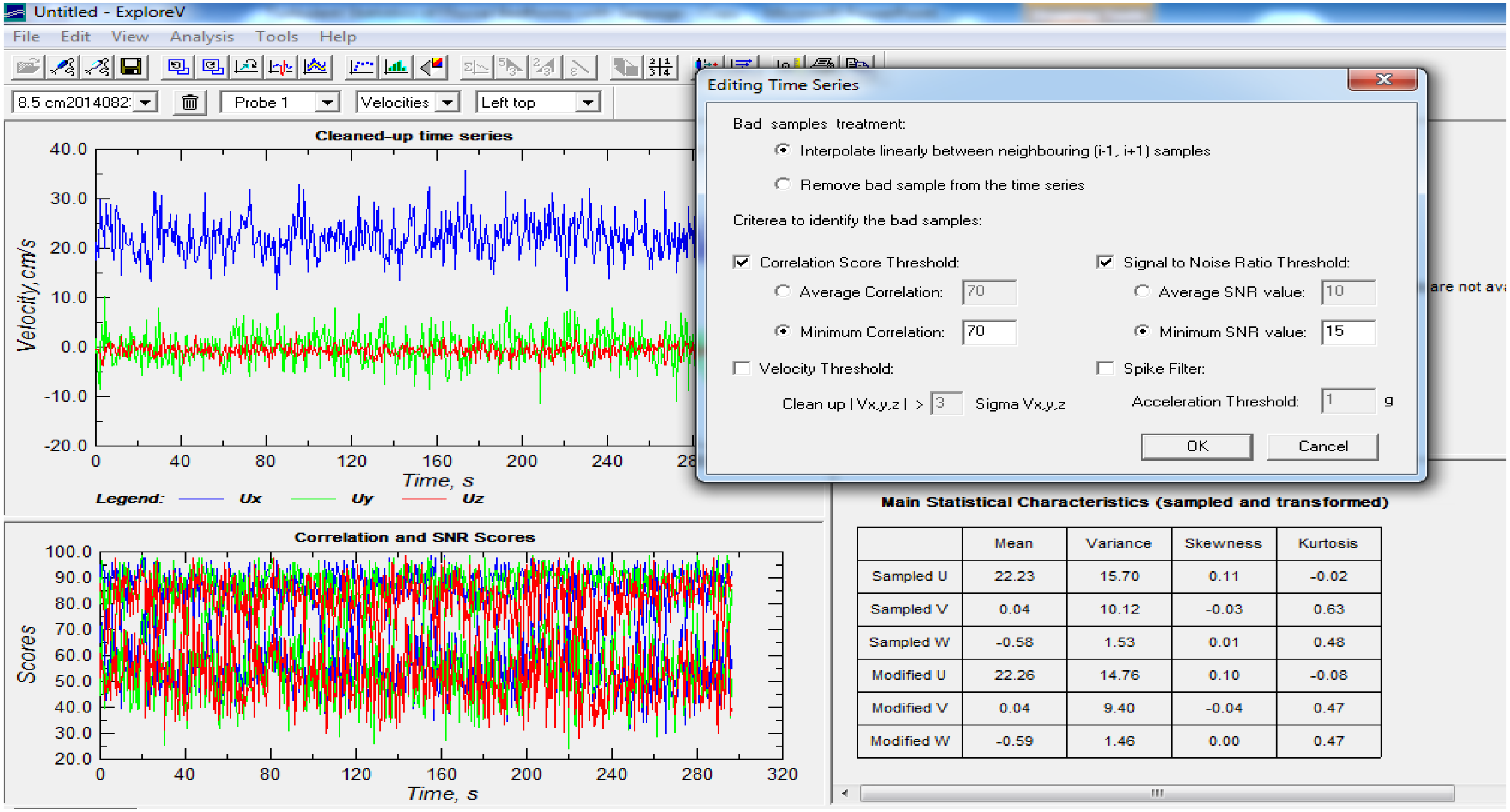


	X	Y	Z1	Z2				
Velocity (cm/s):	26.09	0.27	0.10	0.05	Time:	19:08:05.999	Status:	OK
St.Dev. (cm/s):	2.97	2.42	1.54	1.56	Sample no:	10085	Serial no:	VNO 0955
Amplitude (counts):	113.7	114.7	109.1	95.6	Temp (dgC):	18.96	Probe no:	VCN 8063
SNR (dB):	17.9	19.3	18.9	17.8	Dist (cm):	10.1	Firmware:	1.31 +
Correlation (%):	87.5	86.7	84.0	82.2	Quality:	779	Frequency:	10 MHz

Recording to: C:\Users\Mahesh Patel\Desktop\70 shape\7.5 m\4 cm2014011

Post processing of velocity data

- Data filtration has been done by maintaining SNR (signal to noise ratio) as 15 or above and signal correlation between transmitted and received pair of pulses in between (60-70)% was used



Editing Time Series

Bad samples treatment:

● Interpolate linearly between neighbouring (i-1, i+1) samples

○ Remove bad sample from the time series

Criterea to identify the bad samples:

☑ Correlation Score Threshold:

○ Average Correlation: 70

● Minimum Correlation: 70

☑ Signal to Noise Ratio Threshold:

○ Average SNR value: 10

● Minimum SNR value: 15

☐ Velocity Threshold:

Clean up | Vx,y,z | > 3 Sigma Vx,y,z

☐ Spike Filter:

Acceleration Threshold: 1 g

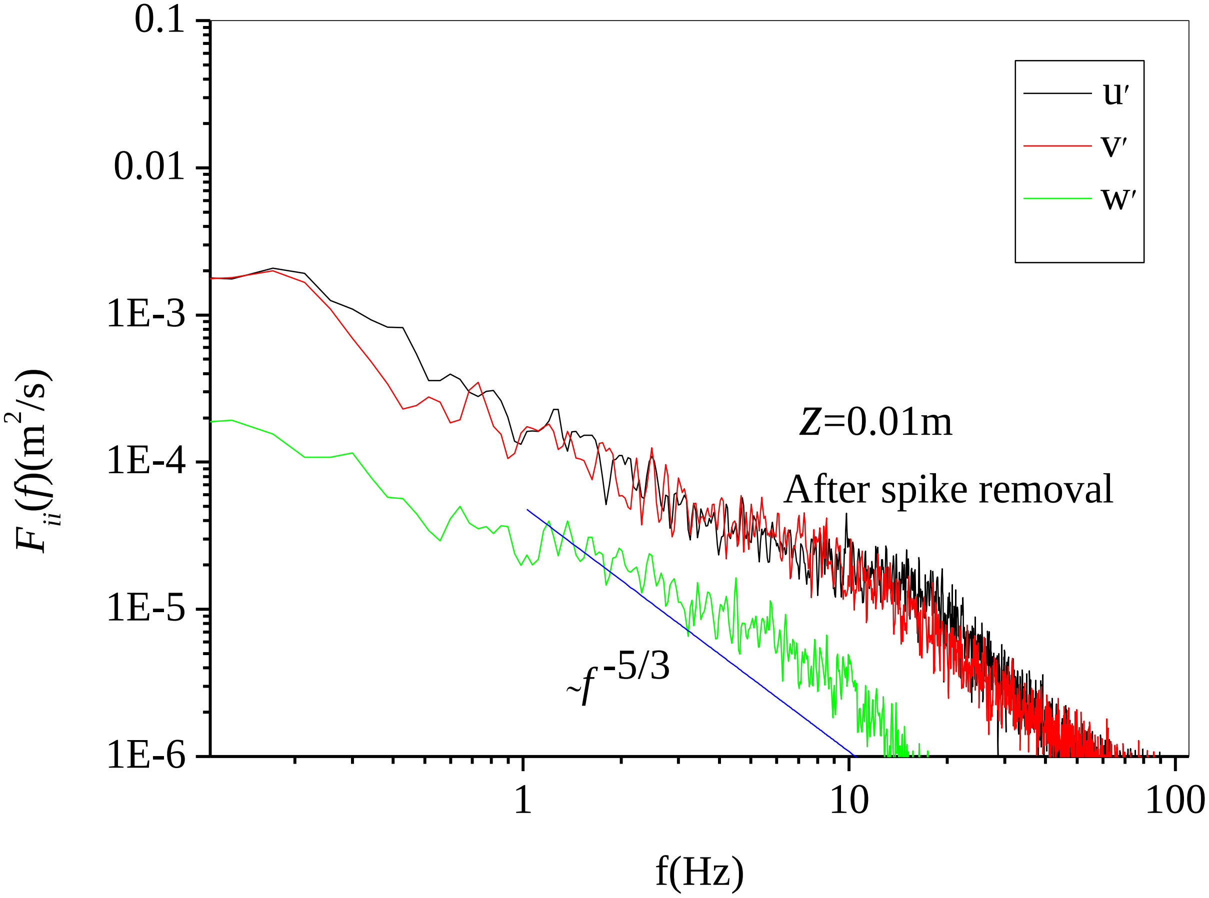
OK Cancel

Main Statistical Characteristics (sampled and transformed)

	Mean	Variance	Skewness	Kurtosis
Sampled U	22.23	15.70	0.11	-0.02
Sampled V	0.04	10.12	-0.03	0.63
Sampled W	-0.58	1.53	0.01	0.48
Modified U	22.26	14.76	0.10	-0.08
Modified V	0.04	9.40	-0.04	0.47
Modified W	-0.59	1.46	0.00	0.47

Contd…

- Goring and Nikora (2002) spike removal technique was used as Kolmogorov's -5/3 scaling law has been fitted in the inertial sub range.
- Acceleration threshold values (1-1.5) were used as trial and error basis.



Results

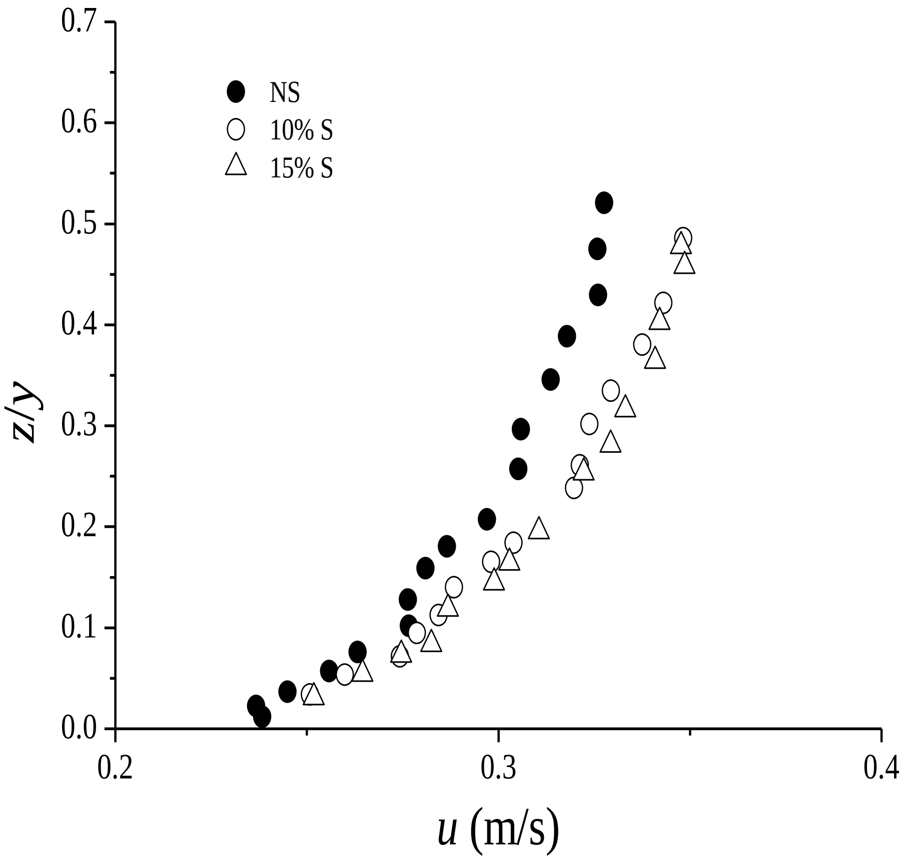
- Time-mean velocity in the direction of flow '*u*' and vertical direction '*w*' were calculated as:

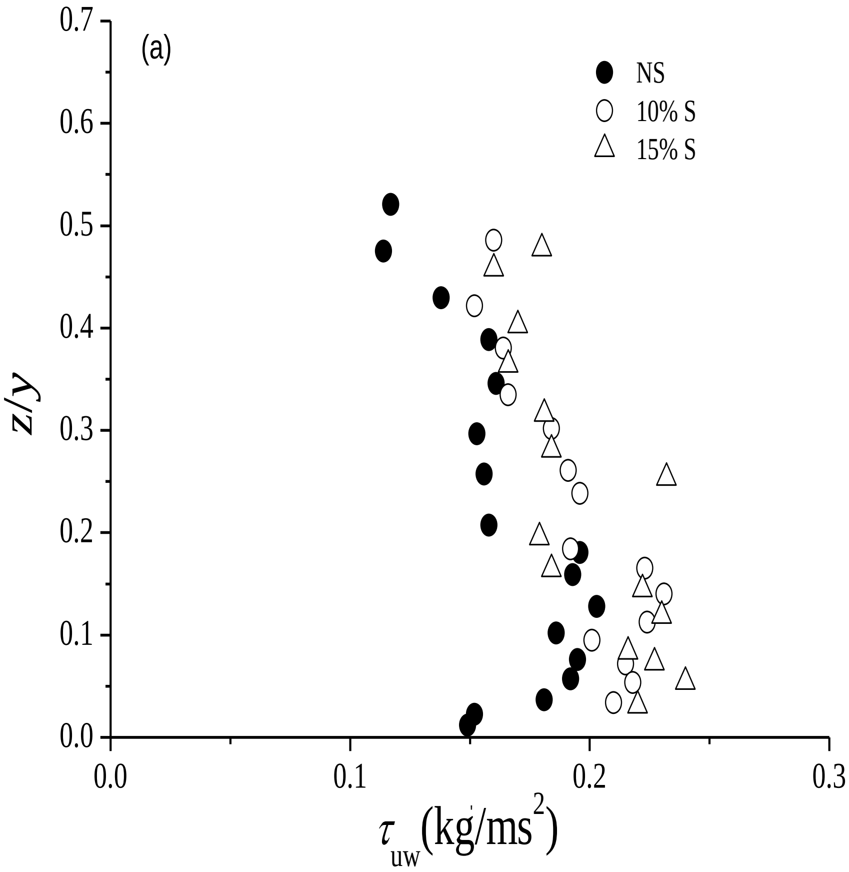
$$u = \frac{1}{n}\sum_{i=1}^{n} u_i \qquad w = \frac{1}{n}\sum_{i=1}^{n} w_i$$

- Reynolds shear stress (RSS)

$$\overline{u'w'} = \frac{1}{n}\sum_{i=1}^{n}(u_i - u)(w_i - w)\,, \qquad \tau_{uw} = -\rho_w\overline{u'w'}$$

Velocity and RSS profile





Observations

- Time averaged velocity increased with downward seepage as compared to no seepage for a particular discharge.

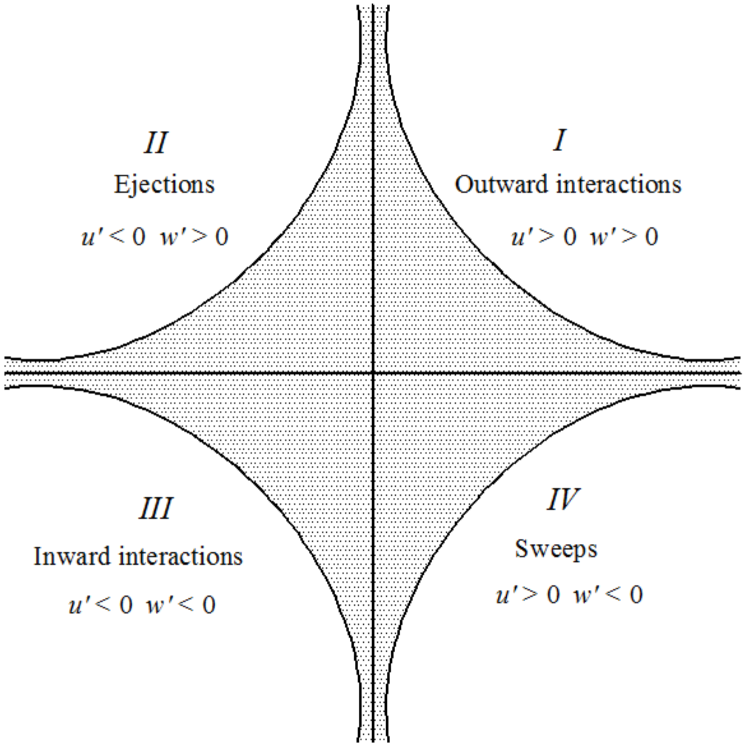
- Quantitative analysis suggests that at very near to the bed, Velocity increases on an average value of 2.36% with 10% seepage. The velocity for 15% seepage case is slightly higher with an average increasing value of 0.40% than the velocity for 10% seepage.

- RSS increases along the channel bed are associated with the provided momentum from the main flow to maintain sediment particle motion overcoming the bed resistance and then again decrease towards the boundary because of the presence of a roughness sub layer in the near bed region.

- The profiles of Reynolds shear stress distribution were found to be similar for both no seepage and seepage runs but the magnitude is higher in both inner and outer layer with the application of seepage.

Quadrant Analysis

- Lu and Willmarth's (1973) technique has been used for quantifying the RSS in each quadrant Q_i (i = 1, 2, 3, 4).



$$\left(|u'w'| = H\sqrt{\left(\overline{u'u'}\right)}\sqrt{\left(\overline{w'w'}\right)}\right)$$

Nezu and Nakagawa, 1993

Contd….

- The Contributions of four particular quadrant (Q_i) and outside the hole-size H is obtained by

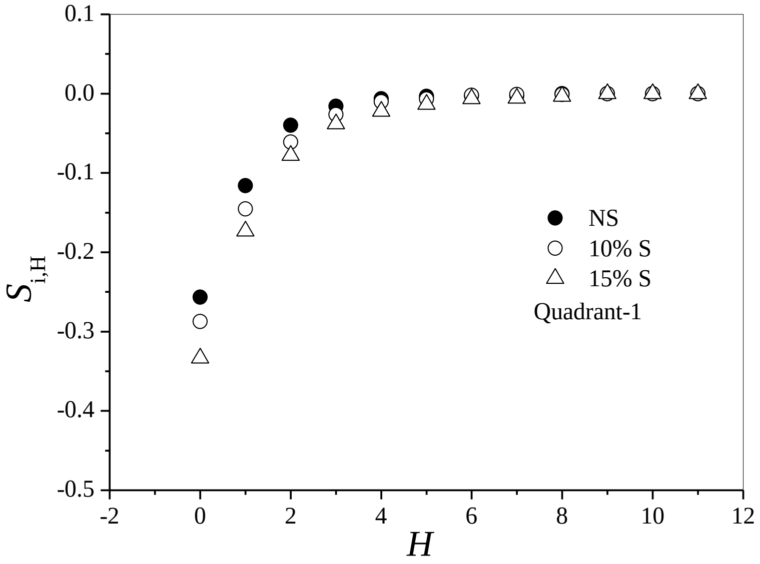
$$(u'w')_{i,H} = \lim_{T\to\infty} \frac{1}{T} \int_0^T u'(t)\, w'(t) \eta_{i,H}(t) dt$$

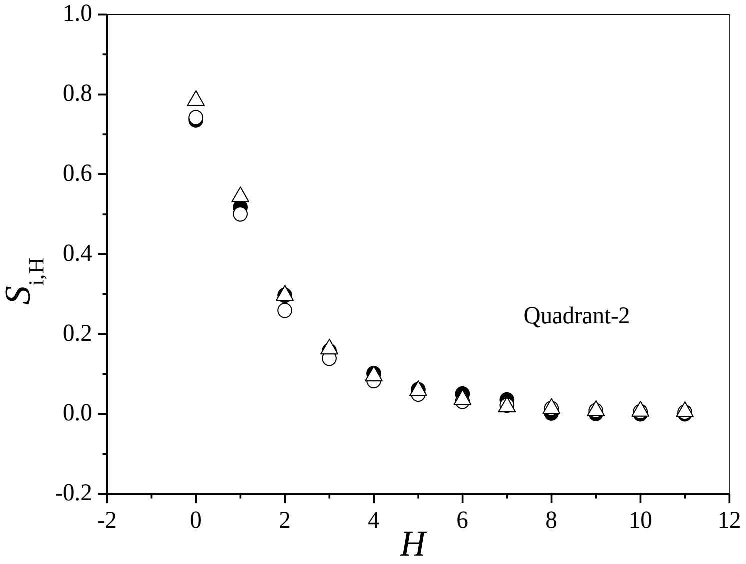
- Where, T is sampling period, t is time and $\eta_{i,H}$ is detection function defined by

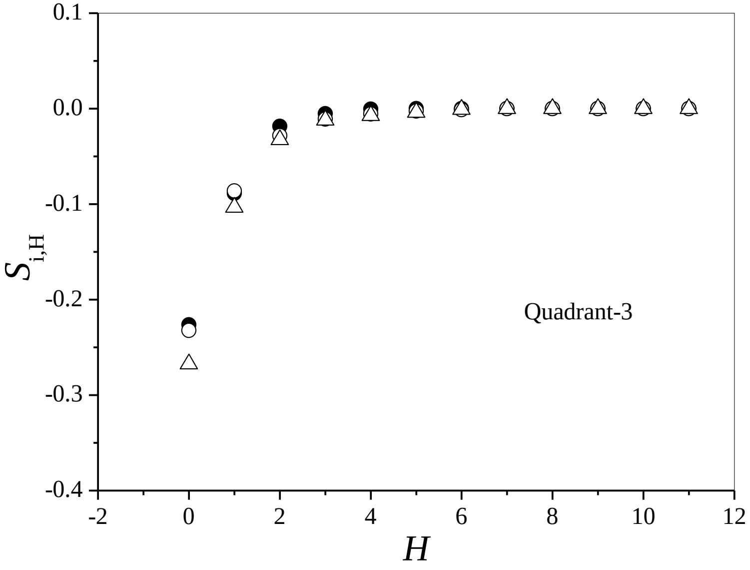
$$\eta_{i,H}(t) = \begin{cases} 1 & \text{when } |u'w'| \geq H\sqrt{\overline{(u'u')}}\sqrt{\overline{(w'w')}} \\ 0 & \text{otherwise} \end{cases}$$

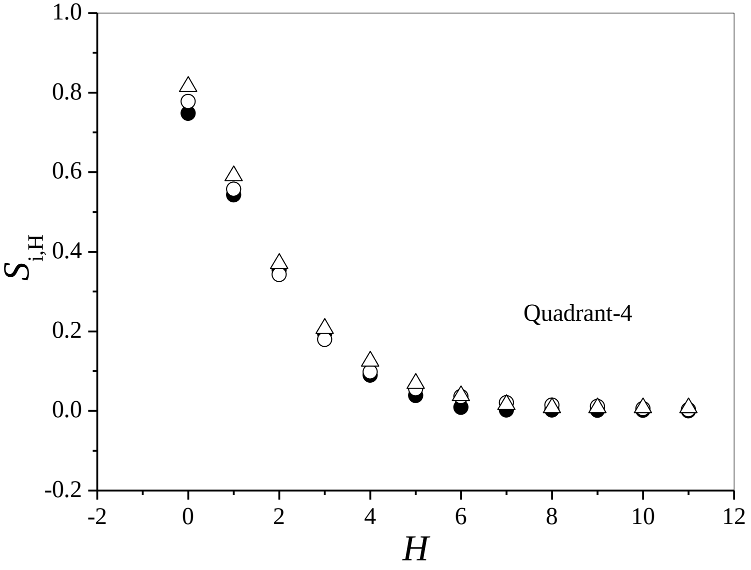
- Distribution of $\overline{u'w'}$ for each event delivers an assessment for fractional contribution $S_{i.H}$ is given by

$$S_{i.H} = \frac{(u'w')_{i,H}}{\overline{u'w'}}$$


0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
$S_{i,H}$
-2
0
2
4
6
8
10
12
H
● NS
○ 10% S
△ 15% S
Quadrant-1


1.0
0.8
0.6
0.4
0.2
0.0
-0.2
$S_{i,H}$
-2
0
2
4
6
8
10
12
H
Quadrant-2


0.1
0.0
-0.1
-0.2
-0.3
-0.4
$S_{i,H}$
-2
0
2
4
6
8
10
12
H
Quadrant-3

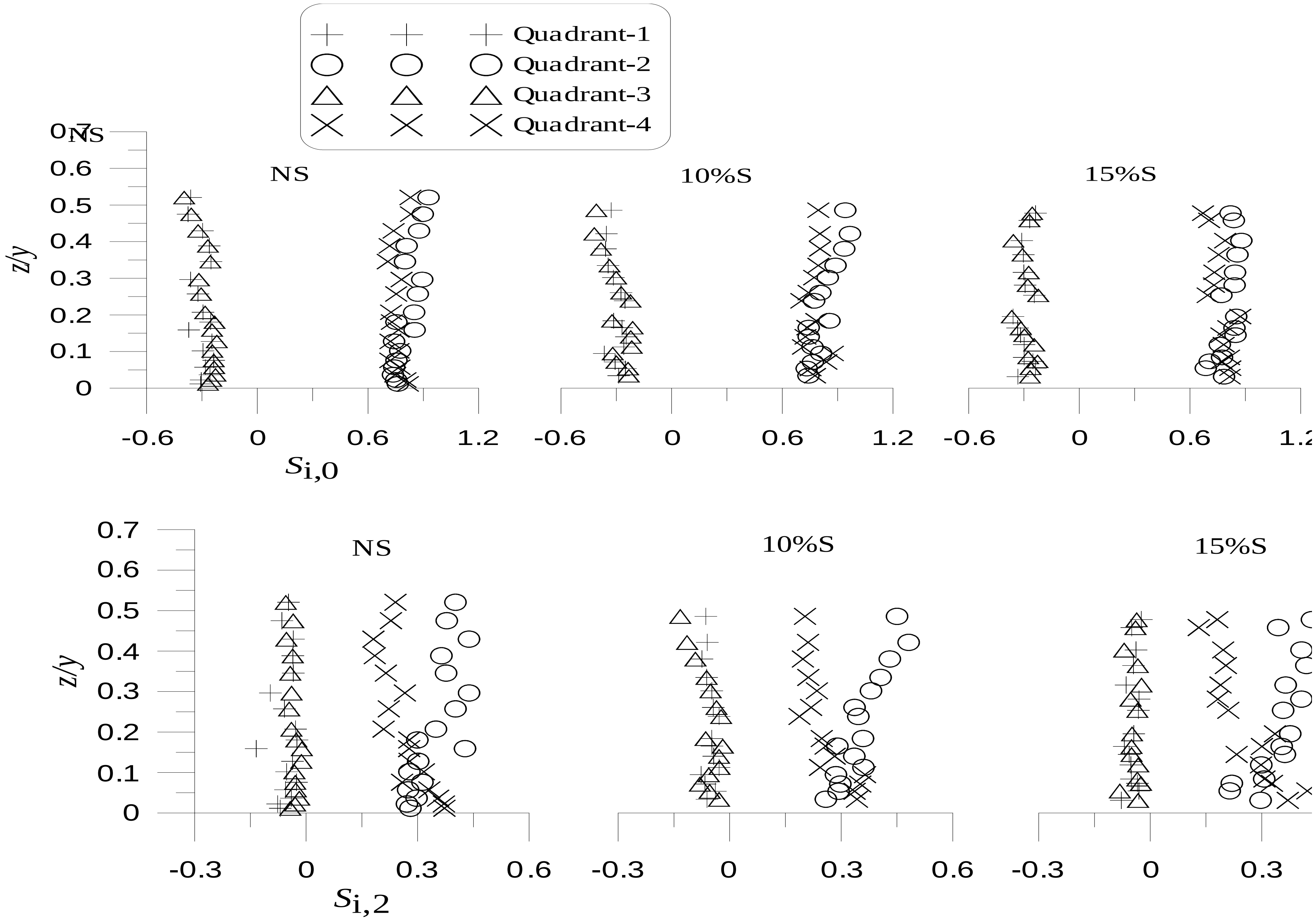

1.0
0.8
0.6
0.4
0.2
0.0
-0.2
$S_{i,H}$
-2
0
2
4
6
8
10
12
H
Quadrant-4

Observations

- The fractional contribution from Q1 and Q3 events vanishes for *H*>7 and H>4 respectively while contribution from the Q2 and Q4 events vanishes for *H*>9 and *H*>10 respectively.

- As a downward seepage causes the withdrawal of momentum in the near bed region causes an increase in Q4 events and decrease of Q2 events, resulting in arrival of a high speed fluid parcel due to acceleration of fluid in stream wise direction.

- With seepage flow, the feebly contributions from both Q1 and Q3 events cease for *H* >8 (10%S case) and *H*>6 (15%S case) while Q2 and Q4 events dominate even for *H* > 11 with sweeps still being the largest contributor towards the production of RSS.


Quadrant-1
Quadrant-2
Quadrant-3
Quadrant-4
NS
NS
10%S
15%S
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
z/y
-0.6
0
0.6
1.2
-0.6
0
0.6
1.2
-0.6
0
0.6
$S_{i,0}$
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
z/y
NS
10%S
15%S
-0.3
0
0.3
0.6
-0.3
0
0.3
0.6
-0.3
0
0.3
$S_{i,2}$

Observations

- ✓Primary contribution is from Q2 and Q4 events and feebly contribution from Q1 and Q3 towards the RSS production.

- ✓ At near bed, the dominance of sweep events over ejection occur while away from the bed, ejection events dominate in contributing to the Reynolds shear stress production.

- ✓The contribution from all bursting events to RSS production in the near bed flow zone increases with the increase of percentage of seepage as compared to that with no seepage run.

- ✓Dominants of sweep events over the ejection events at near the bed increases progressively with the further increase of downward seepage.

- ✓The thickness of the zone of sweep dominance increases in the seepage run which increase momentum exchange from the flow to bed particles due to which sediment transport is increased with the downward seepage as compared to no seepage.

- ✓For hole size *H*=2 for both no seepage and seepage run, the most energetic events Q2 and Q4 have distinct behaviours throughout the flow depth, since the divergence between Q2 and Q4 events gets stronger with *z/y*.

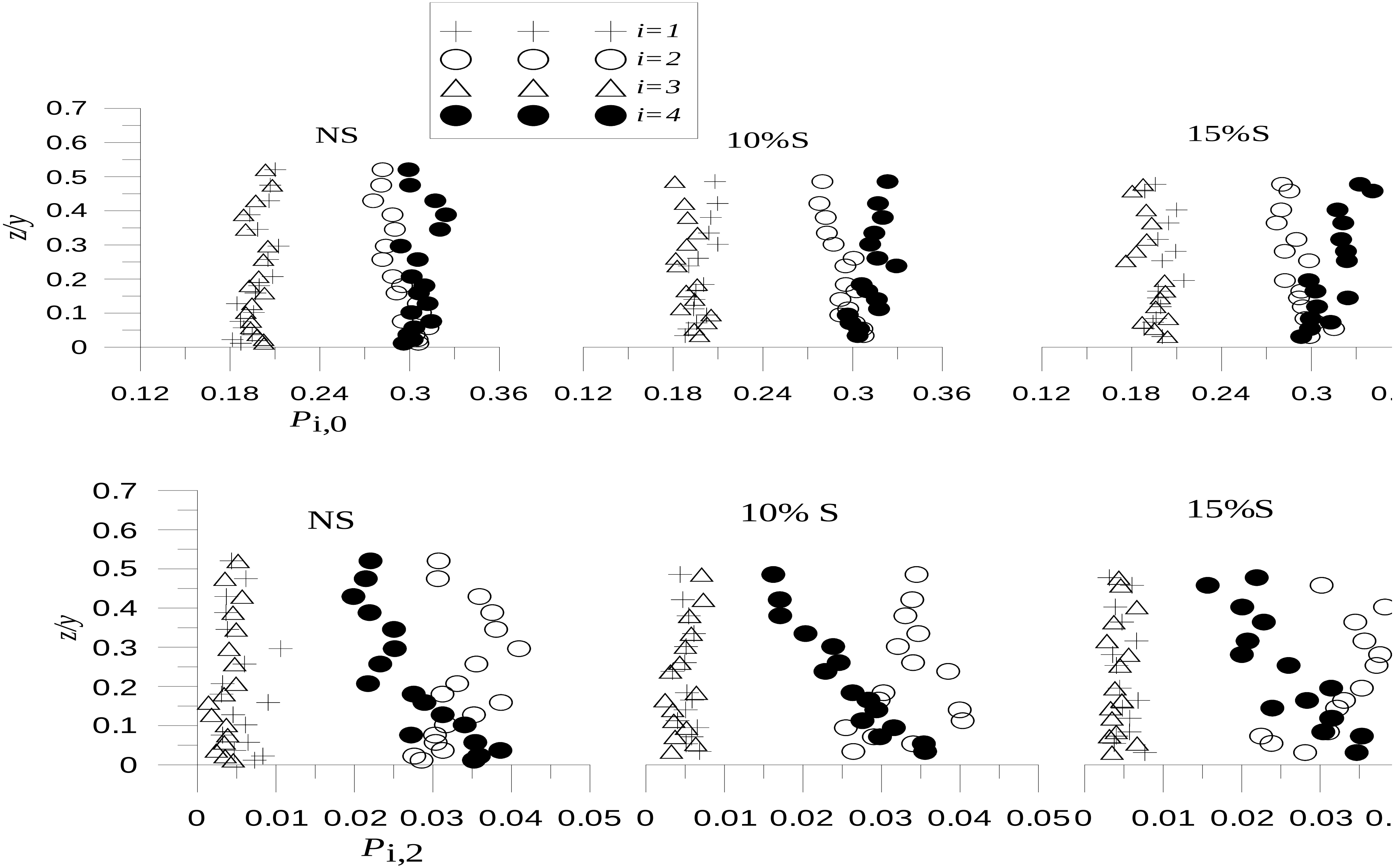
- ✓However, there remains a consensus that there remains a similar predominating feature of Q2 and Q4 events within the wall shear layer while contributions from Q1 and Q3 events remain insignificant.

Probability of Occurrence of Bursting Events

- The probability $P_{i,H}$ of occurrence of the bursting events (Cellin and Lemmin, 2004)

$$P_{i,H} = \frac{\int_{t=0}^{t=T} I_{i,H}\,dt}{\int_{t=0}^{t=T} \left[I_{1,H} + I_{2,H} + I_{3,H} + I_{4,H} \right] dt}$$

$P_{i,H}$ for H=0 and H=2



Observation

- For H=0 and H=2 subjected to no seepage case, values of $P_{1,H}$ and $P_{3,H}$ for Q1 and Q3 events overlap bearing small probabilities.

- Considering H=0, $P_{2,0}$ and $P_{4,0}$ for Q2 and Q4 events are dominant events in the near bed surface for no seepage runs. But, the dominance of $P_{2,H}$ changes to $P_{4,H}$ with an increase in hole size (H=2). Therefore, the strongest bursting events are $P_{4,2}$ (Q4 events) while the most frequent ones are $P_{2,0}$ (Q2 events).

- Interestingly, $P_{\mathrm{i},H}$ (i=1,3) and $P_{4,0}$ remain almost invariant of z/y; whereas $P_{2,0}$ and $P_{4,2}$ decrease with z/y.

- Although there is no significant difference observed in the profiles of $P_{i,H}$ for no seepage and seepage, near boundary values of $P_{4,H}$ (H=0,2) are greater associated with the smaller of $P_{2,H}$ (H=0,2) with seepage than that with no seepage.

Time Scale

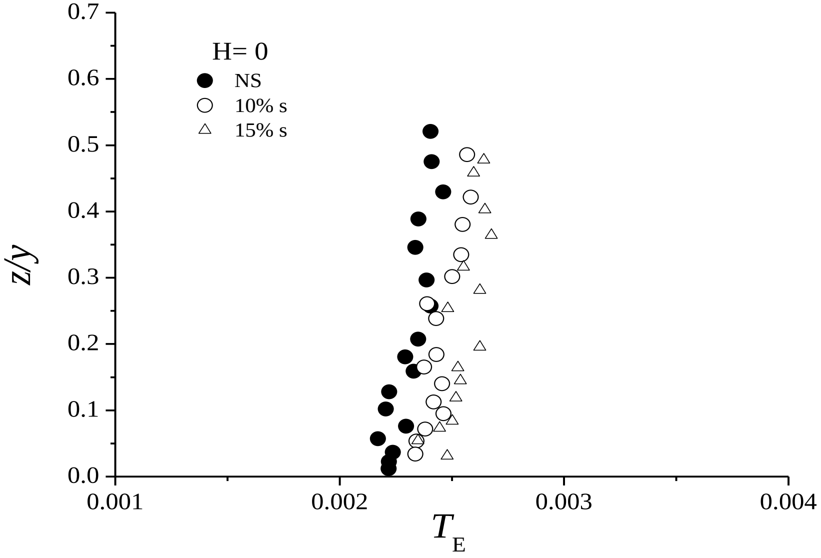
In order to study the time scales of Q2 and Q4 events, the occurrences of bursting events Q2 and Q4 in a sample were counted by keeping a hole size *H* and calculating the number of changeover of the series of (u‘,w‘) in the applicable quadrant. The mean time of occurrence of Q2 and Q4 events t_E and t_S respectively were thus obtained.

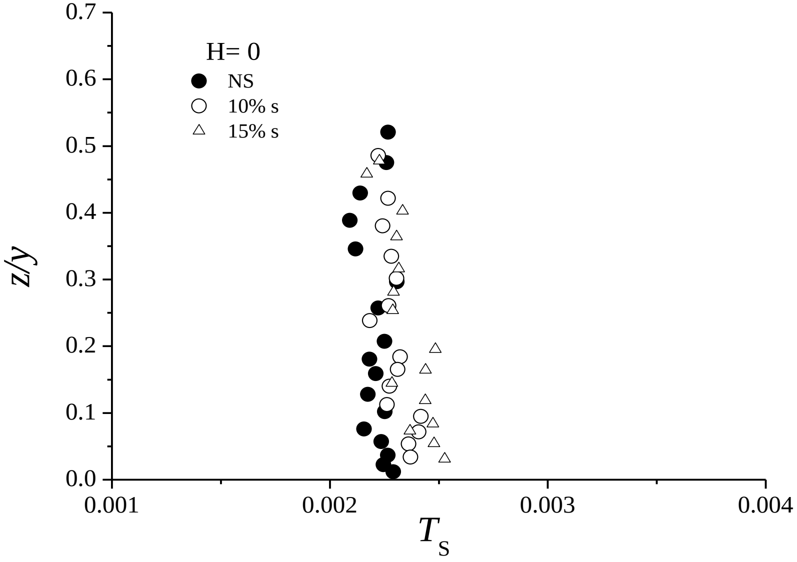
Normalised time scales,

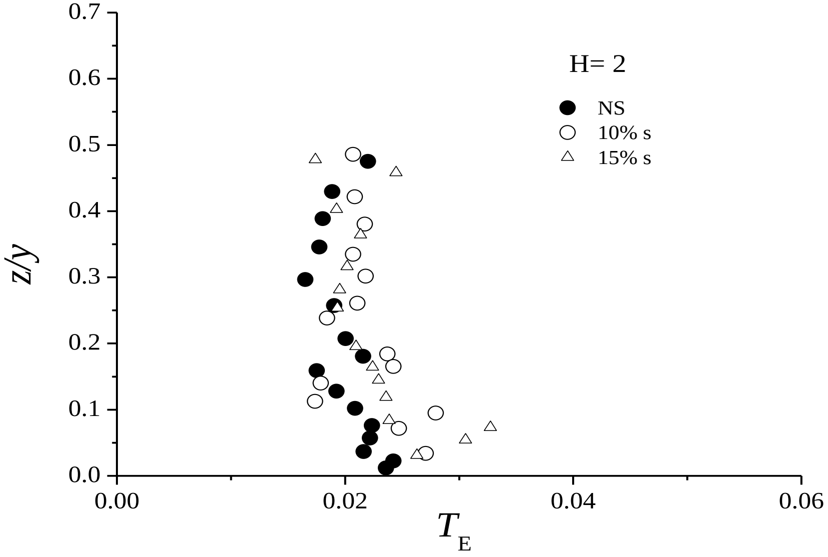
$T_E = t_E u_* / y$

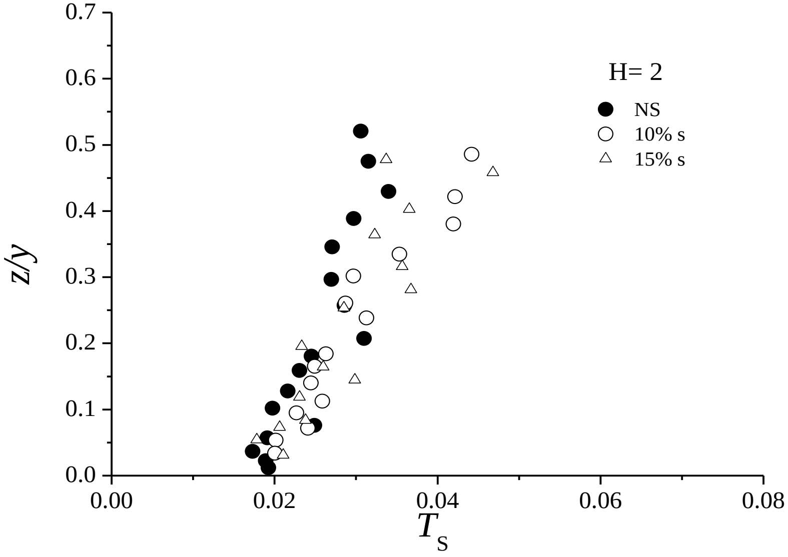
$T_S = t_s u_* / y$

T_E and T_S for H=0 and H=2









Observation

- for H=0, T_E increases with z/y while T_S decreases with z/y. But the phenomenon has been changed for H=2 in case of no seepage and seepage runs. It suggests that the time of occurrence of stronger Q4 events is less than that of stronger Q2 events.

- Both T_E and T_S in seepage are more persistent than those in no seepage.

Conclusions

- The profiles of DA stream wise velocities in the near bed region were increased with the application of downward seepage. This increase in stream wise velocities was enough for increased bed particle mobility with seepage.

- The profile of Reynolds shear stress is also increased with seepage which signifies the enhanced momentum transfer towards the boundary.

- Near the bed surface, the profiles of Reynolds shear stress undergo a damping due to a decreasing level of turbulence fluctuation.

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- In quadrant analysis, the contribution of sweep events towards Reynolds shear stress production near the boundary is increased with increased zone of sweep dominance. This increase in high speed fluid parcel towards the boundary in seepage runs is responsible for higher rate of sediment transport.

- The mean time of occurrence of ejections and that of sweeps in seepage are longer than those in no-seepage.

- In the framework of river engineering, the present study contributes to the knowledge on the link between the turbulent flow and sediment transport with non-uniform flow, which is a governing process on the river morphodynamics.

Thank You