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Investigation of flow velocity distribution in open channels according to specific characteristics under the effect of bed materials: sand, gravel, and concrete

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Abstract

This study presents an in-depth experimental investigation into the effects of varying bed materials on flow velocity distribution in open channels—a critical consideration in hydraulic engineering and sustainable water resource management (Ab Ghani ,2018). Conducted within a controlled laboratory flume setup, the research examined how different sediment types, including vegetation (at varying lengths and arrangements), gravel (of multiple grain sizes), and sand (of different densities), influence hydraulic parameters such as flow velocity, discharge, water depth, hydraulic radius, and Reynolds number. Using flow current meters and hydraulic modelling principles, velocity profiles were produced for each bed condition using flow current meters and the concepts of hydraulic modeling. The results show that bed material dramatically changes sediment transport dynamics, turbulence properties, and flow resistance. Finer sands improved flow velocity because of their smoother surfaces and lower roughness coefficients, but vegetation increased flow resistance because of drag effects. These realizations lay the groundwork for creating channel systems that are more effective and resistant to erosion. These findings offer valuable insights for agricultural irrigation, urban drainage planning, and environmental hydraulics, with applications in sustainable water management and civil infrastructure development (Ohmoto, T. 2020). . The results showed that sea sand achieved the highest flow velocity (0.284 m/s), while dense vegetation (25 cm spacing) and coarse gravel (14 mm) significantly reduced flow due to increased resistance. The Reynolds number ranged between 552 and 5371 depending on the material, indicating transitional to turbulent flow.

Keywords: Open channel, velocity distribution, bed materials, discharge, rough coefficients, Reynolds number.

1. Introduction

Research on sediment movement is an essential field of study for environmental and technical problems, where rivers, marine, and estuary systems, as well as hydraulic structures like dams, are all impacted by sediment flow. Studying sediment movement is challenging due to the complex interactions between the flow and the sediments that comprise the movable bed (Marco, 2024). The roughness of the open channel indicates how much frictional resistance the channel bed material offers to the water flow. The flow velocity in natural channels is impacted by the presence of large, sharp stones, such as bed material, vegetation, obstructions, etc. If a canal is made of silt or smooth clay, water moves more swiftly through it with less roughness. In the case of artificial channels, smooth finishing is required to maintain the required flow velocity. In open channels, the average velocity may be found using Manning's formula (Mofrad, 2024).

Our understanding of sediment transport and flow resistance is enhanced by knowing how flow and vegetation interact to influence velocity and turbulent flow characteristics, including the computation of bed shear stress. Several studies show that the formation of secondary currents is more affected by emergent vegetation than by submerged vegetation (Safari, 2021). It was discovered that the mean streamwise velocity is influenced by Reynolds number, with a higher Reynolds number leading to a higher normalized streamwise velocity in the free surface layer. The buildup of debris in watercourses and hydraulic structures can result in suboptimal performance, obstruction of water flow, erosion, upstream flooding, and structural damage. This has an impact on flood control projects, navigation facilities, and hydropower intakes (Kokkiligadda, 2024).

Moreover, this thinking is driven by the need to assess the impacts of diverse bed materials on stream characteristics within open channels. The experimental work was conducted employing a 4-meter-long concrete channel within the pressure driven lab of Sohar College, where estimations of stream speed, profundity, release, and Reynolds number were carried out employing a stream current meter. Different sorts of bed materials were tried, counting common silt like stream, ocean, and concrete sand, as well as totals of diverse distances across (5 mm, 10 mm, 14 mm), and vegetation mimicked with grass at changing lengths and spacings.

The exploratory comes about affirmed that rougher materials such as long grass or huge rock altogether increment the stream resistance, which decreases speed and increments turbulence. On the other hand, better dregs like ocean sand yielded higher speeds due to lower resistance and smoother channel surfaces. These discoveries strengthen the significance of selecting suitable bed materials when planning pressure driven frameworks for water system, waste, and surge control. Understanding the interaction between stream and silt gives basic knowledge into dregs transport behaviour and makes a difference create economical water administration arrangements.

This examination not only supports hypothetical models such as Manning's condition and the Reynolds number application but too bridges the hole between research facility findings and real-world water powered designing challenges. The bits of knowledge picked up can contribute to the advancement of more effective channel plans, decrease of erosion risks, and enhancement in the accuracy of dregs stream forecasts in characteristic and man-made situations.

Novelty of this research lies in combining controlled flume experimentation with diverse real-world bed materials—such as sea sand, natural gravel, and artificial vegetation—to quantify their hydraulic impacts under identical flow conditions. Unlike prior works focusing on single-material analysis, this study offers comparative insights into how specific grain sizes and plant spacing influence velocity, resistance, and energy loss. The findings contribute to better channel design for irrigation, urban runoff, and sediment control strategies.

Overall, this project will discuss how to:

- Provide adequate knowledge about the effect of flow velocity distribution on open channels for sediment transport.
- Study of the effect of different parameters of water flow velocity in an open channel.
- To analyze the flow velocity distribution in open channels with various bed materials.
- Compare velocity variations and patterns for each material under controlled flow conditions.
- To investigate the effect of bed roughness on the velocity distribution.
- To measure and analyze flow velocity at various positions in the channel using a flow current meter.
- To evaluate the implications of velocity distribution on sediment transport and erosion in open channels with different bed materials.
- Study the influence of bed material on sediment movement and how it impacts the flow characteristics.
- Provide insights for practical applications in hydraulic engineering, particularly for channels designed to minimize erosion or optimize water flow efficiency.

2. Materials & Methods

In this research, we used an open concrete channel to study flow velocity variations resulting from the presence of different sediments with varying properties (Tait, S. 2020). We used three types of sediments: sand, gravel, and grass, each with different conditions and parameters. We also used a flow velocity meter to determine the flow velocity at different points in the open channel. Thus, we can determine the extent to which each type of bed material affects the flow velocity in the open channel based on several parameters related to the flow, the open channel, and the bed material. Based on this, we can observe the effect of different materials' resistance to flow velocity. Through this study, we can analyze the flow velocity distribution in open channels with different bed materials, as well as study the effect of bed roughness on the velocity distribution. This helps provide insights for practical applications in hydraulic engineering, particularly for channels designed to reduce erosion or improve water flow efficiency.

An experimental simulation approach was followed to study the effect of flow velocity using an open water channel supplied with different sedimentation materials.

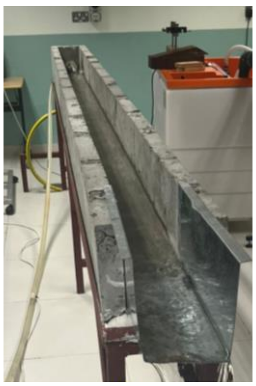

Figure 1: Concrete open channel used in this study, hydrology lab, SU.

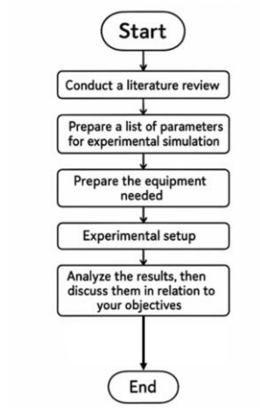

Figure 2: Research Methodology used in this study.

3. Results and Discussion

3.1 flow velocity

As Table 1, and Figure 3 shown below, flow velocity is the primary driver of sediment transport in open channels. The data show that flow velocity varies significantly across bed materials and positions along the channel. The highest velocity was observed in the flow without sediment case (0.284 m/s at 1 m), indicating minimal resistance. In contrast, materials like grass with 25 cm spacing and gravel (10 mm and 14 mm) significantly reduced flow velocity at most points, due to increased flow resistance and turbulence. Different bed materials yielded distinct velocity profiles. Sand types showed uniform velocity distribution, while gravel and grass introduced irregularities and resistance. With consistent discharge, velocity differences reflect bed conditions. Flow without sediment shows the highest velocities, while coarser or vegetated beds reduce flow velocity due to increased resistance (iiMatoušek, V. 2024). .

Table 1:Flow velocity values along the channel for different cases of bed materials.

X(m)	flow velocity (m/s)										
	flow without sediment	Grass (spacing)				Gravel (diameter size)			Sand (specific gravity)		
		25 cm	40 cm	60 cm	no spacing	5 mm	10 mm	14 mm	see sand (0.3)	river sand (0.4)	concrete sand (0.5)
0.5	0.26	0.149	0.225	0.185	0.188	0.169	0.261	0.182	0.126	0.127	0.126
1	0.284	0.275	0.331	0.37	0.281	0.237	0.195	0.192	0.324	0.167	0.324
1.5	0.211	0.218	0.263	0.228	0.226	0.128	0.062	0.18	0.225	0.197	0.225
2	0.186	0.126	0.114	0.157	0.107	0.046	0.055	0.061	0.139	0.099	0.139

2.5	0.035	0.098	0.056	0.105	0.063	0.056	0.013	0.041	0.067	0.1	0.067
3	0.096	0.144	0.141	0.085	0.123	0.013	0.081	0.033	0.1	0.118	0.1
3.5	0.169	0.172	0.187	0.171	0.167	0.026	0.056	0.063	0.175	0.187	0.175
4	0.166	0.029	0.062	0.13	0.243	0.061	0.069	0.121	0.128	0.118	0.128

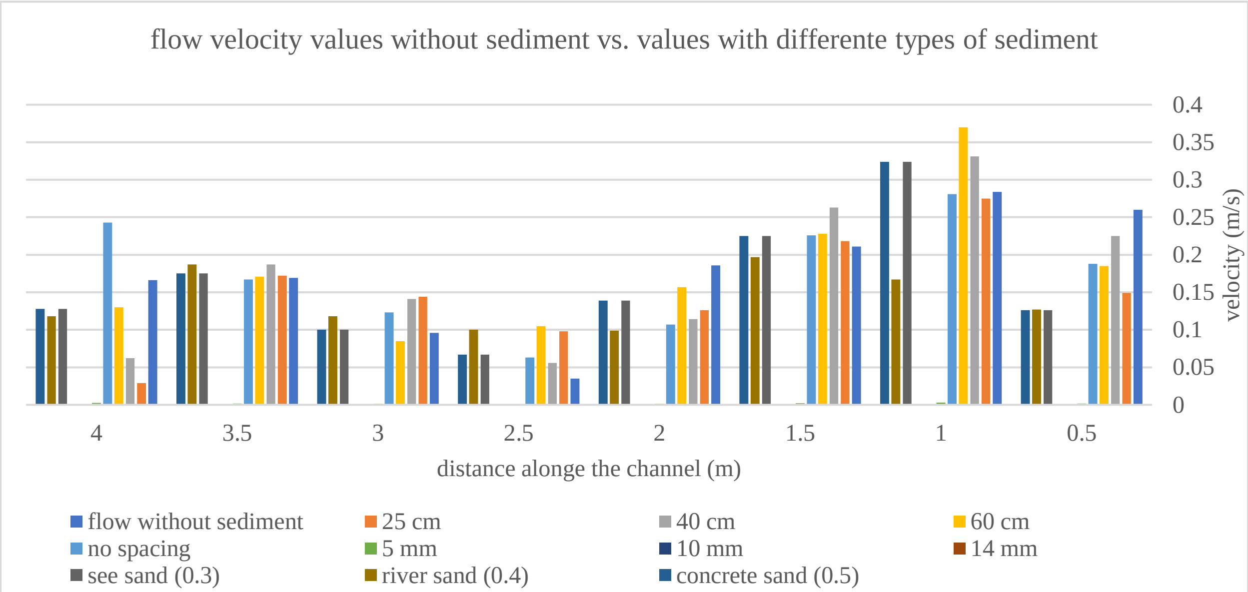

Figure 3:flow velocity values with different types of sediment.

3.2 Manning coefficient (n)

- Bed Roughness and Its Effects on Velocity Distribution

We can analyse from Table 2, that Manning's coefficient (n) indicates bed roughness. Higher roughness coefficients translated to lower velocities and deeper flows, as energy was dissipated by friction and turbulence.

- Velocity Measurements Using a Flow Current Meter

The velocity values were captured using a flow current meter, providing localized data. The meter allowed precise comparisons across materials and helped capture transitional zones.

Table 2: Manning coefficient (n) for different bed materials in open channel.

	Manning coefficient (n)										
		grass (spacing)				**gravel (diameter size)**			**sand (spicific gravity)**		
x(m)	**without sediment**	**25 (cm)**	**40 cm**	**60 cm**	**no spacing**	**5 mm**	**10 mm**	**14 mm**	**see sand (0.3)**	**river sand (0.4)**	**concrete sand (0.5)**
0.5	0.010911	0.017742	0.014921	0.018147	0.014062	0.026334	0.018332	0.026864	0.014109	0.026434	0.026644
1	0.011821	0.014352	0.011506	0.011372	0.014974	0.018778	0.025593	0.029291	0.016985	0.025935	0.013368
1.5	0.019335	0.014644	0.017359	0.015413	0.021172	0.040503	0.078859	0.031694	0.030283	0.023175	0.020291
2	0.025145	0.038804	0.043777	0.031787	0.048453	0.114722	0.103727	0.094819	0.101656	0.051403	0.036611
2.5	0.127154	0.045412	0.083516	0.044542	0.075949	0.089118	0.398803	0.135139	0.075065	0.049906	0.072974
3	0.036607	0.027408	0.028934	0.044806	0.033169	0.359763	0.059071	0.148159	0.036274	0.035659	0.040797

3.5	0.017866	0.020432	0.017072	0.01659	0.019116	0.195728	0.059949	0.075949	0.05389	0.021106	0.017253
4	0.013362	0.09116	0.048699	0.008484	0.011674	0.057611	0.038313	0.03678	0.030675	0.018797	0.020653

3.3 Reynold number (Re)

Velocity profiles strongly affect erosion and deposition. High surface velocities with low bed velocities promote sediment deposition, while uniform high velocities increase erosion risks.
The structure of bed material determines sediment behavior and flow evolution (Davis, J. 2016).. Coarse materials introduce turbulence, trapping sediment, while fine sands promote efficient but potentially erosive flows (Gangadhar Kokkiligadda ,2024).

Table 3:values of Renolds number (Re) for different types of pf flow with different types of bed materials.

x(m)	Reynolds number (Re)										
	without sediment	grass (spacing)				gravel (diameter size)			sand (specific gravity)		
		25 (cm)	40 cm	60 cm	no spacing	5 mm	10 mm	14 mm	see sand (0.3)	river sand (0.4)	concrete sand (0.5)
0.5	2089.286	1077.108	2327.586	1913.793	1359.036	2668.421	4594.133	3309.091	1888.235	1313.793	1303.448
1	2937.931	3626.374	4137.5	5370.968	4079.032	3742.105	3656.25	4306.542	3865.691	2531.649	4911.702
1.5	2924.185	2091.279	4314.844	2526.136	3978.061	2541.176	1127.273	4125	2781.122	3232.031	3691.406
2	3163.918	2290.909	2137.5	2943.75	2124.265	937.8641	1260.417	1427.064	1012.5	1911.386	2683.663
2.5	552.6316	1547.368	952.5773	1786.082	1108.929	1050	258.0882	899.2925	1741.667	1875	1218.182
3	1063.636	1898.901	1954.076	1062.5	1704.62	221.134	1425.765	600	1683.871	1712.903	1385.87
3.5	1491.176	1905.682	1793.895	1374.107	1602.035	501.9802	579.3103	1108.929	802.2472	2465.934	1544.118
4	922.2222	209.6386	547.0588	253.2468	1952.679	675.8523	498.7952	1910.526	1843.207	655.5556	925.3012
AVERAGE	1893.123	1830.907	2270.63	2153.823	2238.582	1542.317	1675.004	2210.806	1952.318	1962.281	2207.961
Type of flow	Transitional	Transitional	Turbulent	Turbulent	Turbulent	Transitional	Transitional	Turbulent	Transitional	Transitional	Turbulent

Implications for Design and Management:

- Channels with light sediments need erosion control measures (riprap, vegetation).
- Heavier sediments might be used to reinforce bed stability (gabion mattresses, concrete lining).
- Understanding sediment properties helps in predicting deposition zones, scour areas, and channel evolution.

Type of material	Parameter	Effect on Velocity
Grass	**Spatial spacing**	Denser vegetation → more drag → **slower flow**. Sparse grass allows more velocity through gaps.
Gravel	**Diameter size** (5 mm, 10 mm, 14 mm)	Larger diameter → **greater roughness height** → **higher resistance**, thus **lower average velocity**.
Sand	**Grain size** (fine, medium, coarse)	Coarser sand increases bed roughness → **reduces velocity** due to higher friction.

Specific gravity	Higher SG → more compact and stable bed → slightly **lower turbulence**, potentially **higher velocity** near bed.
Packing and bed compaction	Loose sand increases roughness → **reduces flow velocity**. Tightly packed → **smoother flow**.

4. Conclusion

In conclusion, this study shows that bed material properties—such as type, size, density, and arrangements significantly affect flow velocity in open channels (Absi, R. 2024). Coarse gravel and dense sand increased resistance and reduced flow speeds, while vegetation, especially when long and dense, disrupted flow patterns and decreased average velocity.

The research highlights the importance of selecting appropriate bed materials to improve hydraulic efficiency, control erosion, and support sustainable channel design. It also provides valuable data for engineers and supports the use of eco-friendly materials. Future studies could expand on this work by examining unsteady flows, varied channel shapes, and using advanced modelling tools.

This study examines how different bed materials—such as grass, gravel, and sand—affect flow velocity distribution in open channels, using a flume-based experimental setup. Key hydraulic parameters like velocity, Reynolds number, and Manning's coefficient were measured to assess flow behaviour under various sediment conditions.

Main findings:

- Vegetation and coarse gravel increased flow resistance due to drag and turbulence.
- Fine sand allowed smoother, more stable flow.
- Bed roughness, material size, and arrangement significantly influenced velocity profiles.

The research has practical value for designing sustainable flood control, irrigation, and drainage systems. It also supports eco-friendly engineering by encouraging the use of natural materials. The study offers valuable data for scaling up to real-world applications and lays the groundwork for future research using more complex flow conditions and predictive modelling tools (Smith, J. 2020).

Author contribution: All authors have contributed, read, and agreed to the published version of the manuscript results.

Conflict of interest: The authors declare no conflict of interest.

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