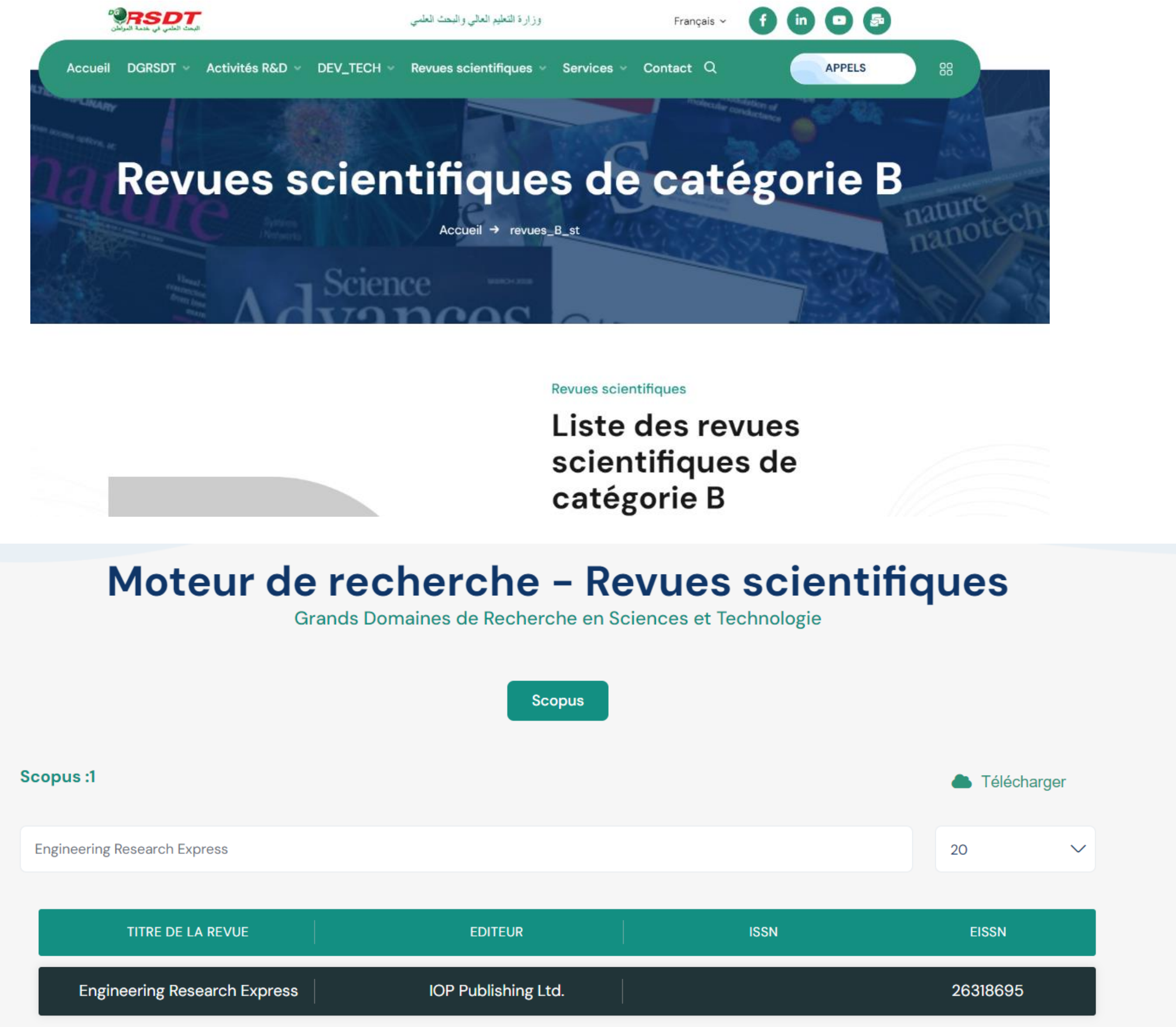
Article 6 **:**
Publié dans la revue *Engineering Research Express*.

- **Éditeur :** Institute of Physics Publishing
- **E-ISSN :** 2631-8695
- **Période de couverture par Scopus :** de 2019 à 2025
- **Domaine scientifique :** Génie général
- **Impact facture : 1.8 (2024);**
- **Lien d'article** ***DOI 10.1088/2631-8695/ae1082***
- **Type de source :** Revue scientifique (*Journal class B lien :* ***https://www.dgrsdt.dz/fr/revues_B_st?revue=SCOPUS&search=Engineering+Research+Express***)



Engineering Research Express

PAPER

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Published 15 October 2025 •

Engineering Research Express, Volume 7, Number 4

Citation Seyfeddine Benabid *et al* 2025 *Eng. Res. Express* **7** 045106

DOI 10.1088/2631-8695/ae1082

Article PDF

Engineering Research
Express

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To cite this article: Seyfeddine Benabid *et al* 2025 *Eng. Res. Express* **7** 045106

IOP Publishing Eng. Res. Express 7 (2025) 045106 https://doi.org/10.1088/2631-8695/ae1082

Engineering Research Express

PAPER

RECEIVED
19 May 2025

REVISED
27 September 2025

ACCEPTED FOR PUBLICATION
7 October 2025

PUBLISHED
15 October 2025

Effect of transverse bottom slope and bed roughness on hydraulic jump flow in an asymmetrical trapezoidal stilling basin: an experimental approach

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Keywords: energy dissipation, non-rectangular stilling basin, hydraulic jump, dissipative elements

Abstract

Controlling hydraulic jump is critical for maximizing energy dissipation, minimizing erosion, and improving the performance of stilling basins. This study presents the first comprehensive experimental investigation of the combined effects of transverse bed slope and surface roughness on hydraulic jump characteristics, energy dissipation, and free-surface flow dynamics in an asymmetrical trapezoidal channel. An innovative stilling basin configuration was implemented, featuring a transversely inclined rough bed ($\theta = 17°$) with vertical sidewalls and three distinct roughness heights (14.32, 24.47, and 30.76 mm), tested across a wide range of Froude numbers ($3.3 < F_{r1} < 9.4$). The experimental setup allowed the exploration of previously unexplored three-dimensional flow structures, revealing pronounced secondary turbulence that contributed significantly to energy dissipation. The results demonstrated that increasing bed slope and roughness substantially altered hydraulic jump behavior, reducing the sequent depth ratio by approximately 31.16% and the secondary depth by nearly 18.6% compared to classical jump. Additionally, the roller length decreased by an average of 39.11%, while greater slope and roughness height increased relative energy dissipation by 9.53% compared to a classical jump. Beyond the experimental work, new empirical relationships were developed to predict key hydraulic jump parameters, achieving error margins of $\pm$ 10% to $\pm$ 20% and closely matching the observed data, offering practical guidance for the design of efficient and resilient stilling basins.

List of symbols

g	Acceleration due to gravity $[m/s^2]$. V_1 Average velocity in section 1 $[m/s]$.
k_s	Relative roughness height $[-]$. k_e Roughness element height $[mm]$.
E_1	Charge in the first section of the jump $[m]$. b Channel width $[m]$.
E_2	Charge in the last section of the jump $[m]$. Q Flow discharge $[m^3/s]$.
d_1	Average depth of upstream sequences $[m]$. A_2 Second section of water $[m^2]$.
d_2	Average depth of downstream sequences $[m]$. A_1 First section of the water $[m^2]$.
D	Difference in transverse bed elevation $[m]$. f_1, f_2, f_3, f_4, f_5 Functional symbol.
ρ	Water density $[kg/m^3]$. μ Dynamic viscosity $[N.s/m^2]$
E_L	Energy loss associated with hydraulic jump $[m]$. x_1 The jump toe position $[m]$.