Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

In-Plane Flow Capacity of a Polypropylene Drainage Geocomposite for Engineering Design under Hydromechanical Conditions

Lynith C. Datukon
Ateneo de Davao University
Ken P. Cosares
Ateneo de Davao University
Alejandro H. Espera Jr.
ahesperajr@addu.edu.ph
Ateneo de Davao University https://orcid.org/0000-0002-3294-1847
Ernie Jane Y. Jalem
Ateneo de Davao University
Johann Vincent D. Miro
Ateneo de Davao University
Khent Ronald S. Olamit
Ateneo de Davao University
Lindsay D. Sefuentes
Ateneo de Davao University
Jenith L. Banluta
Ateneo de Davao University
Renyl B. Barroca
Ateneo de Davao University

Research Article

Keywords: drainage geocomposite, in-plane flow capacity, transmissivity, hydraulic gradient, seating pressure, design specification

Posted Date: May 5th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9597407/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: The authors declare no competing interests.

Abstract

When a polypropylene drainage geocomposite is specified for a retaining wall or a landfill drainage blanket, the flow capacity reported on the product data sheet is often obtained under hydraulic and confinement conditions that differ from field service. This mismatch is not a minor calibration issue because it can shift the apparent factor of safety by more than threefold. This technical note examines that problem using a manufacturer-supplied EN ISO 12958 dataset comprising 72 observations across two core thicknesses (5 and 10 mm), two hydraulic gradients (0.10 and 1.0), and two seating pressures (200 and 500 kPa), combined factorially to yield eight treatment combinations. Flow capacity and transmissivity ($\theta = q/i$) are reported for all treatment combinations and interpreted against the allowable-flow frameworks of GRI GC8 and ASTM D7931. The 10 mm core at gradient 1.0 delivered about 3.9 times the flow of the same core at gradient 0.10, not the tenfold increase implied by Darcy-type proportionality. Average transmissivity decreased consistently with increasing gradient, indicating transition to a non-laminar in-plane flow regime at $i = 1.0$. The flow reduction from 200 to 500 kPa reached 3.3-fold for the 10 mm core under the steeper gradient, large enough to invalidate specifications anchored to low-pressure catalog data. Practical guidance is provided for retaining-wall backfill drains, landfill drainage blankets, and pavement subdrainage layers.

1 Introduction

Geocomposite drainage panels have displaced granular drainage layers across a wide range of geotechnical and geoenvironmental applications over the past three decades. A drainage geocomposite only a few millimeters thick can replace hundreds of millimeters of compacted aggregate while offering more consistent hydraulic performance, simpler installation logistics, and a smaller construction footprint [1], [2]. Retaining walls, embankment subdrainage, landfill liner and cover systems, and pavement edge drains routinely specify drainage geocomposites as primary or secondary drainage elements [3]–[6].

The main challenge lies at the interface between laboratory testing and design. Every declared flow-capacity value is tied to the test conditions under which it was obtained, including a specific hydraulic gradient, a specific normal stress applied through standardized rigid platens, and a temperature-corrected flow measurement taken after a prescribed seating period [7]. These dependencies are often not stated clearly in product data sheets. As a result, a specifier comparing products tested at $i = 1.0$ has no direct basis for judging how those products would perform at the lower gradients typical of landfill caps or under the higher confinement pressures encountered beneath retaining-wall backfills. Although GRI GC8 and ASTM D7931 address long-term performance through reduction factors for creep, installation damage, and clogging [8], those frameworks still assume that the baseline laboratory value is relevant to the hydraulic and mechanical conditions expected in service.

Recent work has probed various aspects of this problem. Demand-capacity modeling for pavement geocomposite drainage has highlighted the importance of gradient-matched test data [3]. Transmissivity

under actual soil confinement rather than rigid platens has been shown to differ meaningfully from standard-test values [5]. Performance in tunnel drain geometries [6] and numerical drainage characterization in unsaturated fine-grained soils [9] each adds a dimension to the picture. These studies collectively point to the fact that gradient, confinement, and core geometry interact in ways that single-condition test data cannot capture. Yet a direct, condition-by-condition comparison that puts a specific number on the potential misspecification error, across the gradient and pressure ranges most relevant to drainage design, has received limited attention in concise, practice-oriented papers.

That is the gap addressed here. Using a manufacturer-supplied EN ISO 12958 dataset of 72 measurements across eight gradient-thickness-pressure combinations, this technical note reports flow capacity and transmissivity for each condition, ranks the relative importance of the governing factors and their interactions through factorial analysis, and translates the results into specification guidance for representative drainage applications.

2 Product Description and Test Background

The product considered in this study is a polypropylene drainage geocomposite comprising a three-dimensional drainage core laminated with nonwoven polypropylene geotextile filter layers on both faces. The core provides interconnected in-plane flow channels, while the geotextile facings retain surrounding soil particles and reduce intrusion into the drainage pathways. This configuration differs from granular drains because the hydraulic response depends not only on the intrinsic geometry of the core but also on how that geometry interacts with hydraulic gradient and compressive loading. To improve generalizability and maintain product confidentiality, the commercial identity and proprietary core profile are not disclosed.

Flow-capacity tests were conducted in compliance with EN ISO 12958 [7], which prescribes rigid platen loading, a fixed drainage length, and temperature correction to 20°C. Flow capacity q is reported in liters per meter width per second (L/m/s). Hydraulic transmissivity ($\theta = q/i$) provides a gradient-normalized measure of the material's in-plane conductance. For a strictly Darcian response, transmissivity would remain constant with gradient; departures from that constancy indicate that inertial effects are becoming important and that performance can no longer be scaled linearly across gradients. All tests were performed in an ISO 9001-accredited laboratory. Equipment was calibrated before each test campaign, and any specimen showing leakage, unstable flow readings, or incomplete saturation was excluded from the dataset prior to analysis.

3 Experimental Design

Three factors were each tested at two levels (Table 1): core thickness (5 and 10 mm), hydraulic gradient (0.10 and 1.0), and seating pressure (200 and 500 kPa). These levels are usually encountered in design and are representative of typical field conditions. Gradients ranging from 0.10 to 1.0 span flow conditions from gentle drainage slopes in landfill caps and pavement edge drains to steeper hydraulic

gradients relevant to retaining-wall drainage systems. Seating pressures of 200–500 kPa correspond approximately to moderate-to-high overburden levels that may develop in practical geotechnical applications [10].

Each of the $2^3 = 8$ treatment combinations received nine replicates, giving 72 measurements in total. Nine replicates per cell is not excessive for EN ISO 12958 data: within-combination scatter is a real feature of this test, and pooling it into a proper error term is essential for honest significance testing. Run order was randomized in JMP 17 (SAS Institute, Cary, NC) to guard against time-related confounding. The full three-factor interaction model was fitted by analysis of variance at $\alpha = 0.05$. Residual diagnostics (normal quantile plots, residual-versus-predicted plots, and Levene's test) confirmed that the standard assumptions were adequately satisfied.

Table 1
Test factors and levels, with representative field equivalents

Factor	Low	High	Unit	Field context
Core thickness (T)	5	10	mm	Within typical product range of 5–25 mm
Hydraulic gradient (G)	0.10	1.0	—	Landfill blankets through retaining-wall drains
Seating pressure (P)	200	500	kPa	≈ 10–25 m equivalent overburden depth

4 Flow Capacity and Transmissivity Results

Mean flow capacity and average transmissivity for each treatment combination are listed in Table 2 and ranked in Fig. 1. The highest mean flow recorded, 3.305 L/m/s for the 10 mm core at gradient 1.0 and 200 kPa, is 66 times the lowest, 0.050 L/m/s for the 5 mm core at gradient 0.10 and 500 kPa. Both lie within realistic laboratory and field-relevant ranges. This 66-fold span shows that a single catalog flow value, without its corresponding test conditions, cannot serve as a defensible engineering specification.

The average transmissivity data reveal an equally important trend. For the 10 mm core at 200 kPa, θ equals 8.51 L/m/s at gradient 0.10 but only 3.31 L/m/s at gradient 1.0 (Table 2, Fig. 2). The same pattern, namely higher transmissivity at lower gradient, is observed for every thickness-pressure combination in the dataset. The observed 2.6-fold reduction in transmissivity with increasing gradient indicates that inertial effects become increasingly important at higher heads and that Darcy-type proportionality is no longer an adequate descriptor for performance scaling under these conditions.

The actual flow ratio between gradient 1.0 and gradient 0.10 is 3.9 for the 10 mm core at 200 kPa, not the tenfold implied by Darcy proportionality. For the 5 mm core at 500 kPa, the same ratio is 10.8, which happens to resemble proportionality but reflects coincidence rather than laminar physics: the gradient-specific transmissivities are not equal, as Table 2 makes clear. These observations matter directly in practice. When a specifier uses a gradient 1.0 test value and then applies it to a gradient 0.10 field

situation by multiplying by 0.10, the result is internally inconsistent if the two gradients span a flow-regime transition.

Table 2
Mean in-plane flow capacity and transmissivity for each treatment combination (n = 9 per cell)

T (mm)	Gradient	P (kPa)	Mean q (L/m/s)	θ = q/i (L/m/s)	Rank
10	1.0	200	3.305	3.31	1
10	1.0	500	1.002	1.00	2
5	1.0	200	0.998	1.00	3
10	0.10	200	0.851	8.51	4
5	1.0	500	0.541	0.54	5
10	0.10	500	0.289	2.89	6
5	0.10	200	0.211	2.11	7
5	0.10	500	0.050	0.50	8

5 Engineering Interpretation

5.1 Factor rankings and what they mean for product selection

Table 3 and Fig. 4 summarize where the variance in measured flow capacity resides. Gradient and thickness are the significant main effects, whereas seating pressure is not significant as an isolated main effect. This should not be interpreted to mean that confinement is unimportant; rather, its influence depends strongly on the specific thickness-gradient combination under consideration.

The dominant term in the model is the thickness-gradient interaction ($F = 42.70$, $p < 0.001$), which exceeds the F-ratios for gradient alone (18.98) and thickness alone (12.55). The hydraulic advantage associated with the thicker core is therefore not constant across test conditions. At gradient 1.0, the 10 mm core outperforms the 5 mm core by roughly 2.5 times in pooled flow (Fig. 3), whereas that advantage narrows at gradient 0.10. This result necessitates a shift in specification logic: drainage geocomposites should be ranked using condition-specific performance data rather than isolated catalog constants.

Table 3
Effect test results from the 2^3 factorial ANOVA (α = 0.05)

Model term	Sum of squares	F-ratio	p-value	Engineering interpretation
T × G (dominant interaction)	6.259	42.70	< 0.001	Thickness benefit is gradient-dependent; the two factors must be evaluated jointly
Gradient (G)	2.782	18.98	< 0.001	Primary driver of flow magnitude; also determines flow regime
T × G × P	2.354	16.06	0.0002	Pressure sensitivity is highest where gradient and thickness favour high flow
Thickness (T)	1.840	12.55	0.0007	Significant individually; magnitude of benefit depends on gradient level
G × P	0.360	2.46	0.122	Not significant
T × P	0.196	1.34	0.252	Not significant
Seating pressure (P)	0.118	0.80	0.374	Not significant as main effect; enters through the three-way interaction

5.2 Confinement: not a main effect, but not a minor one

Seating pressure reduced flow in every single treatment cell. What prevented it from reaching significance as a main effect was the sheer variability of the reduction across conditions. For the 10 mm core at gradient 1.0, the step from 200 to 500 kPa cuts mean flow from 3.305 to 1.002 L/m/s, a 3.3-fold suppression. The same step on the 5 mm core at gradient 1.0 gives only a 1.8-fold reduction. That disparity is captured by the significant three-way interaction (F = 16.06, p = 0.0002; Fig. 5). The engineering interpretation indicates that pressure sensitivity is highest precisely where flow capacity is highest, i.e., for the product variant that a designer would most likely select.

Consider a retaining wall backfill drain behind a 15 m wall. Confinement at mid-height readily reaches 300–500 kPa. If the specification was built on a 200 kPa test value, the available capacity at depth could be roughly one-third of what the design assumed. That is not a factor of safety issue; it is a specification error, and the present data gives it a concrete number. The practical design rule simply suggests matching the test pressure to the expected field confinement or applying an explicitly derived correction factor. Relying on a long-term creep reduction factor does not solve this problem, because the creep factor is intended to account for time-dependent deformation under sustained load, not for the initial flow reduction that occurs when the drain is loaded to a pressure above its test pressure.

5.3 Guidance for three application types

Table 4 shows the findings in a format directly usable for specification practice. For each of the three application types, the table identifies the typical field gradient and confinement, recommends the most

representative test condition from the present dataset, and notes the main risk of using a mismatched test value. One point deserves emphasis across all three scenarios: the allowable-flow expression in GRI GC8 [8] applies creep, installation-damage, and clogging reduction factors to a measured flow value to arrive at an allowable design flow. All of those factors assume the starting test value is representative of field service conditions. If the gradient or pressure in the test differed substantially from those in the field, then the reduction factors correct only for durability, not for the hydraulic mismatch. The mismatch must be resolved first, at the specification stage, before GRI GC8 is applied.

Table 4
Specification guidance for three drainage geocomposite application types

Application	Typical field gradient	Typical confinement	Best test match	Primary risk of mismatch
Retaining wall backfill drain	0.5–1.0	200–500 kPa	G = 1.0, P = 500 kPa	3.3× flow overestimate at depth if 200 kPa test value is used for a high-confinement application (10 mm core)
Landfill drainage blanket	0.05–0.10	100–300 kPa	G = 0.10, P = 200 kPa	Linear scaling from G = 1.0 test data overestimates field flow by up to 2.6× due to non-Darcian flow regime at high gradient
Pavement subdrainage	0.05–0.30	50–200 kPa	G = 0.10, P = 200 kPa	Product ranking by thickness can reverse at shallow gradient; steep-gradient catalogue comparison may not reflect field performance

5.4 Scope and limitations

The dataset covers one product family tested at two discrete levels per factor, and the results should be interpreted within that experimental window. Two-level factorial designs are well suited for identifying dominant effects and interactions, but they do not resolve curvature or threshold behavior beyond the tested ranges. A second limitation arises from the use of rigid platens in EN ISO 12958 testing. Although this boundary condition improves repeatability, it simplifies field confinement. In practice, particularly in fine-grained soils, geotextile intrusion into the drainage core void space may further attenuate in-plane flow, especially under higher seating pressures. The reported values should therefore be interpreted as threshold hydraulic-performance indicators under standardized laboratory confinement rather than absolute field capacities.

6 Conclusions

The results demonstrate that the in-plane hydraulic performance of a polypropylene drainage geocomposite is strongly condition-dependent and cannot be represented adequately by a single catalog value. Across the eight treatment combinations, mean flow capacity varied from 0.050 to 3.305 L/m/s, corresponding to a 66-fold range under gradients and seating pressures that are all relevant to

engineering design. As shown in Figs. 1 and 5 and summarized in Table 2, this spread is large enough to alter product ranking and design confidence if laboratory conditions are not aligned with the intended field application.

A second conclusion concerns the coupled influence of thickness and hydraulic gradient. The factorial analysis identified the thickness-gradient interaction as the dominant model term, exceeding either main effect alone (Table 3 and Fig. 4). Figure 3 shows that the hydraulic advantage of the 10 mm product is much more pronounced at the steeper gradient than at the lower gradient. This means thickness should not be treated as a standalone proxy for drainage performance. Instead, product comparison and specification should be based on condition-specific hydraulic response under the gradients expected in service.

The transmissivity results further indicate that performance scaling is non-linear across the tested hydraulic conditions. For the 10 mm product at 200 kPa, average transmissivity decreased from 8.51 L/m/s at a gradient of 0.10 to 3.31 L/m/s at a gradient of 1.0. Similar reductions were observed for the other factor combinations (Fig. 2), indicating departure from simple Darcy-type proportionality at the higher gradient. In practical terms, a design based on gradient conversion from an unmatched catalog value can misrepresent both available discharge capacity and the degree of safety built into the drainage system.

Finally, the results clarify how confinement should be treated in design. Although seating pressure was not significant as an isolated main effect, its influence became substantial under combinations that also favored high flow, particularly for the thicker product at the steeper gradient (Fig. 5). The reduction from 3.305 to 1.002 L/m/s between 200 and 500 kPa for the 10 mm product shows that baseline test conditions must be matched first to the anticipated field gradient and confinement. Only after that alignment should long-term reduction factors such as those in GRI GC8 be applied. For retaining walls, landfill drainage layers, pavement subdrainage, and related geotechnical systems, the central design implication is straightforward: specify drainage geocomposites using hydraulically and mechanically relevant test conditions rather than detached single-point catalog declarations.

Declarations

Author contributions

L.C. Datukon and K.P. Cosares: analysis and writing of original draft. A.H. Espera Jr.: analysis, writing of final draft, visualization, supervision, review, and editing. E.J.Y. Jalem, J.V.D. Miro, K.R.S. Olamit, and L.D. Sefuentes: conceptualization, methodology, experimentation, data curation, and review. J.L. Banluta and R.B. Barroca: supervision, review, and editing.

Acknowledgements

The authors thank the geocomposite manufacturer that supplied the EN ISO 12958 test dataset. This work was completed as part of the Master of Engineering program at Ateneo de Davao University, Davao City, Philippines.

Data availability

The dataset was provided by a drainage geocomposite manufacturer for academic analysis under a confidentiality agreement. Treatment-combination means and statistical outputs are presented in full within the article. Raw specimen-level data are available from the corresponding author on reasonable request, subject to the manufacturer's approval.

Competing interests

The authors declare no competing financial interests or personal relationships that could have influenced the work reported in this article.

References

1. Springer N (2026) International Journal of Geosynthetics and Ground Engineering: Aims and scope. https://link.springer.com/journal/40891. Accessed 14 Apr 2026
2. Shukla SK (2021) Geosynthetics and ground engineering: sustainability considerations. Int J Geosynth Ground Eng 7:17. https://doi.org/10.1007/s40891-021-00258-5
3. Kalore SA, Sivakumar Babu GL (2023) Hydraulic design of granular and geocomposite drainage layers in pavements based on demand-capacity modeling. Geotext Geomembr 51(5):131–143. https://doi.org/10.1016/j.geotexmem.2023.01.002
4. Saride S, Huchegowda BK, Vyas S (2022) Evaluation of drainage coefficients for 2D and 3D-geocomposite embedded subbase layers. Geotext Geomembr 50(6):1110–1119. https://doi.org/10.1016/j.geotexmem.2022.05.006
5. Ngo DH, Horpibulsuk S, Buritatum A, Udomchai A, Samingthong W, Arulrajah A, Kulariyasup W (2021) Hydraulic transmissivity of geocomposite confined with soils. Measurement 175:109106. https://doi.org/10.1016/j.measurement.2021.109106
6. Jo Y, Cha W, Yoo WK et al (2024) Assessment of geosynthetic materials for tunnel drains: laboratory tests and image analyses. KSCE J Civ Eng 28:4844–4852. https://doi.org/10.1007/s12205-024-1690-3
7. ISO (2020) ISO 12958-1:2020 Geotextiles and geotextile-related products—Determination of water flow capacity in their plane—Part 1: Index test. ISO, Geneva
8. Geosynthetic Research Institute (2013) GRI GC8: Standard guide for determination of the allowable flow rate of a drainage geocomposite (Rev. 1). GRI, Folsom, PA

9. Jana A, Dey A (2025) A numerical investigation of drainage characteristics of nonwoven geotextile in unsaturated fine-grained soil. Int J Geosynth Ground Eng 11:53. https://doi.org/10.1007/s40891-025-00660-9
10. Koerner RM (2012) Designing with geosynthetics, 6th edn. Xlibris, Bloomington, IN
11. Bear J (1972) Dynamics of fluids in porous media. Elsevier, New York
12. Freeze RA, Cherry JA (1979) Groundwater. Prentice-Hall, Englewood Cliffs
13. Stormont JC, Ray C, Evans DD (2001) Transmissivity of a nonwoven polypropylene geotextile under suction. Geotext Geomembr 19(5):289–303. https://doi.org/10.1016/S0266-1144(01)00004-5
14. Shukla SK, Sharma RS (2009) Effect of seating time on transmissivity and permittivity of nonwoven geotextiles. Geotext Geomembr 27(6):466–472. https://doi.org/10.1016/j.geotexmem.2009.05.001
15. Montgomery DC (2019) Design and analysis of experiments, 10th edn. Wiley, Hoboken

Figures

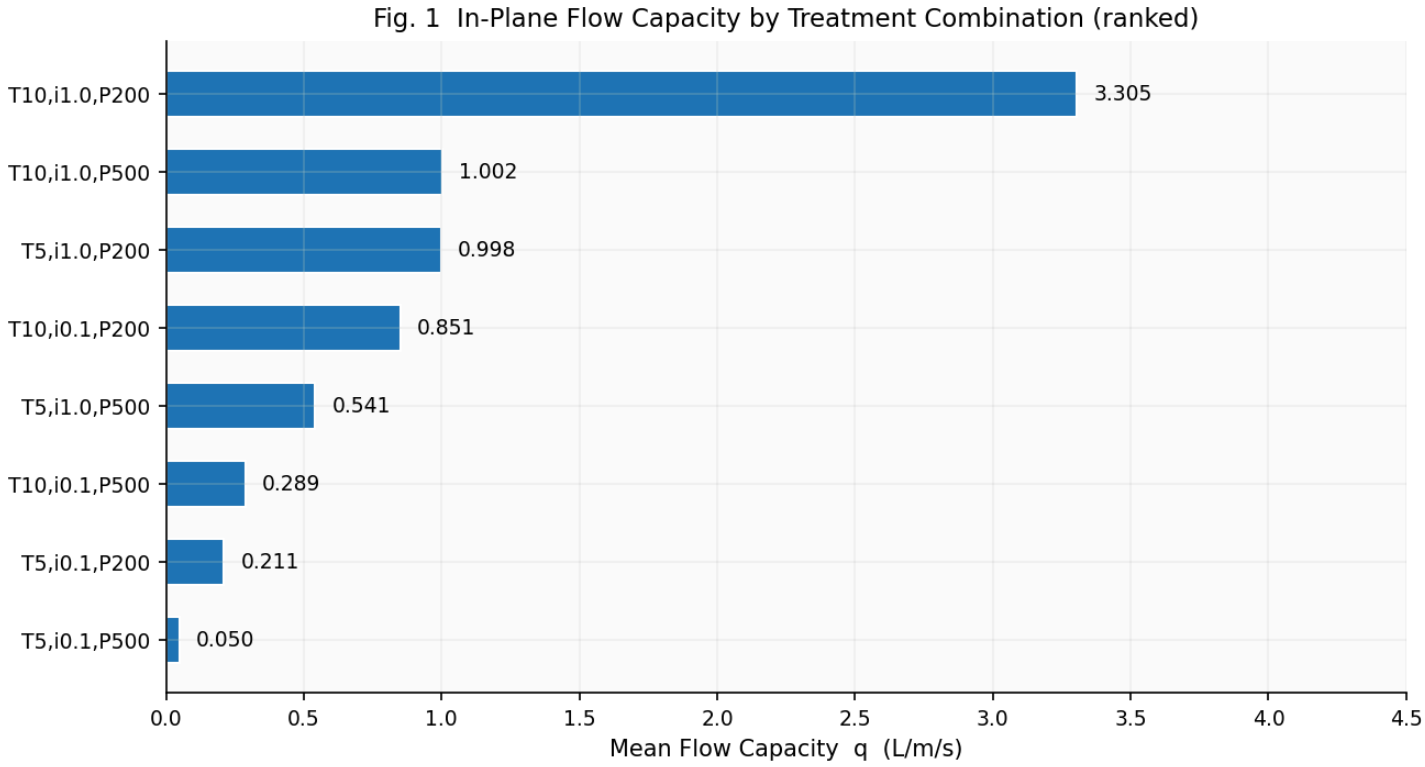


Figure 1

Mean in-plane flow capacity ranked across the eight treatment combinations. The 66-fold span from the highest to lowest condition demonstrates that a single catalog flow value is insufficient for design without its accompanying test conditions.

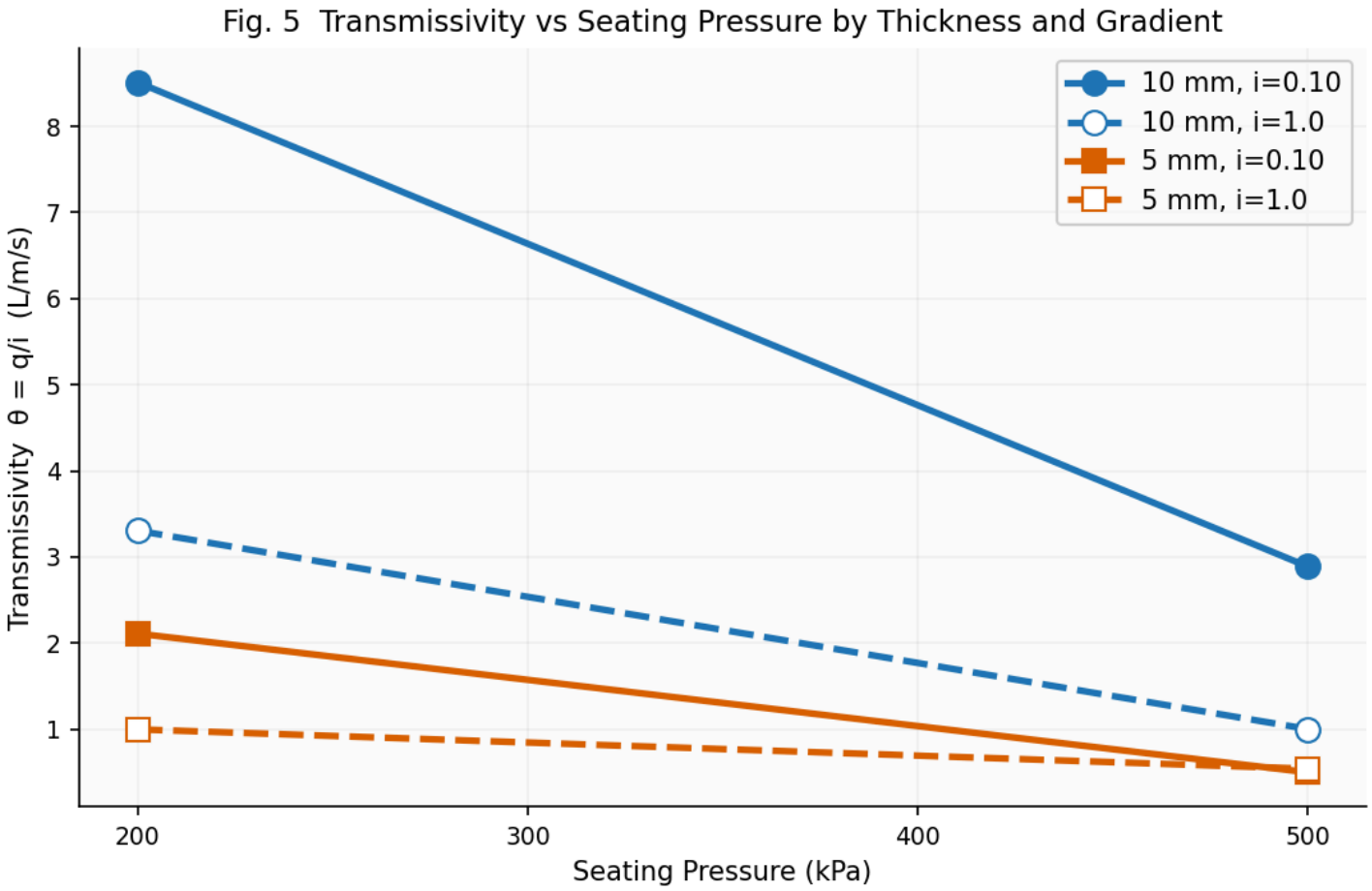


Figure 2

Transmissivity (θ = q/i) as a function of seating pressure. θ is higher at gradient 0.10 than at 1.0 for every thickness and pressure level, indicating departure from linear gradient scaling under the steeper hydraulic condition.

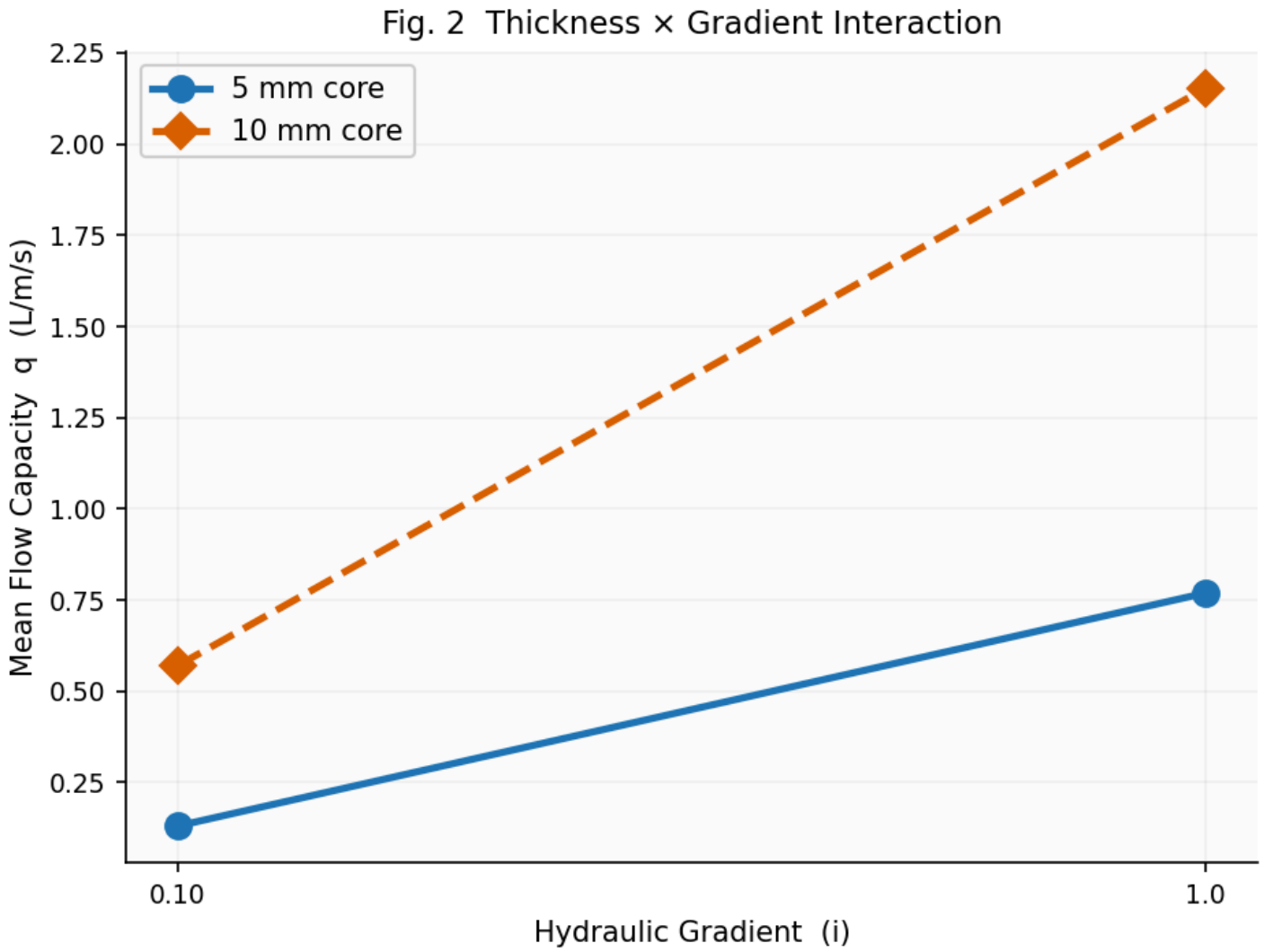


Figure 3

Thickness-gradient interaction plot. Non-parallel profiles confirm that the hydraulic advantage of the 10 mm core narrows substantially at gradient 0.10 and cannot be inferred reliably from steep-gradient test data alone.

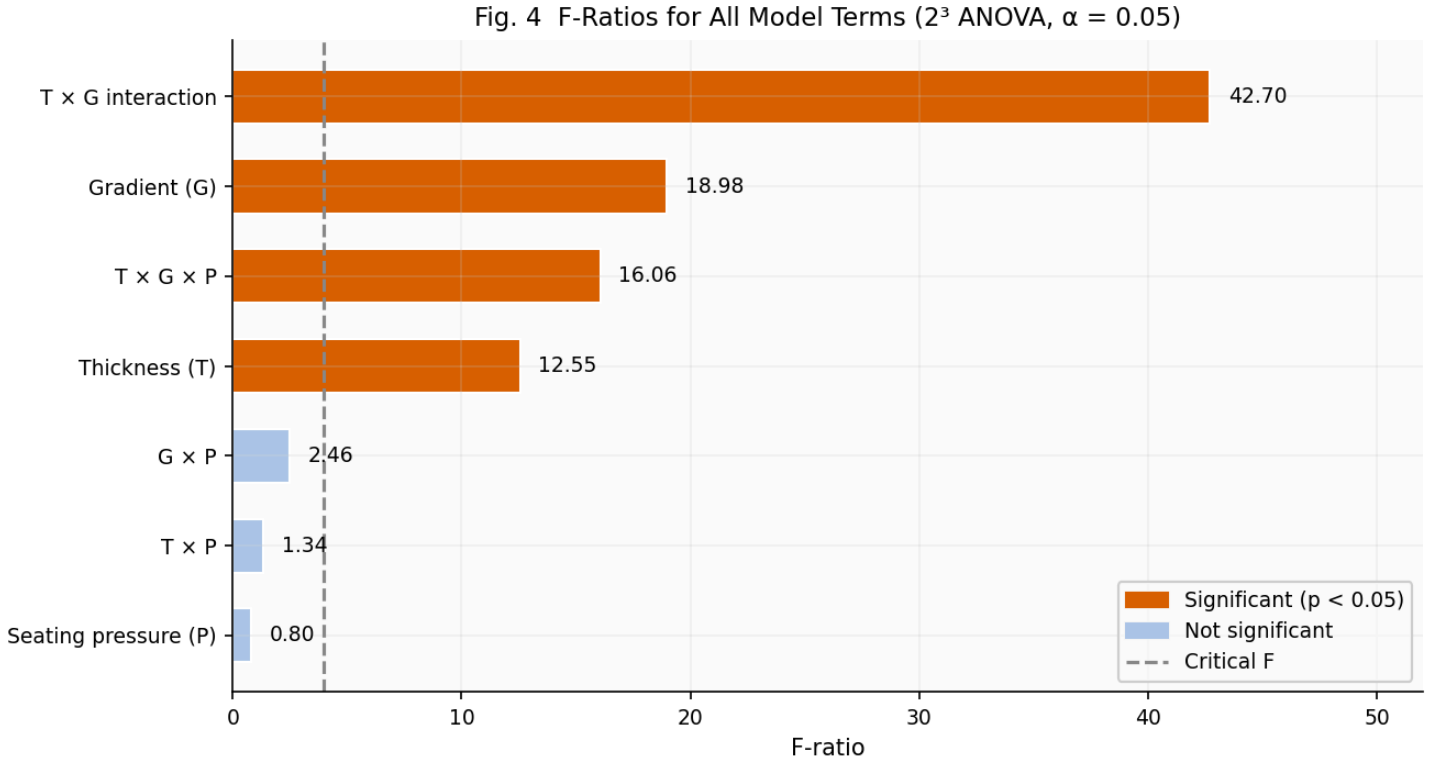


Figure 4

F-ratios for all model terms. The T×G interaction is larger than either main effect, confirming that thickness and gradient must be evaluated together rather than independently.

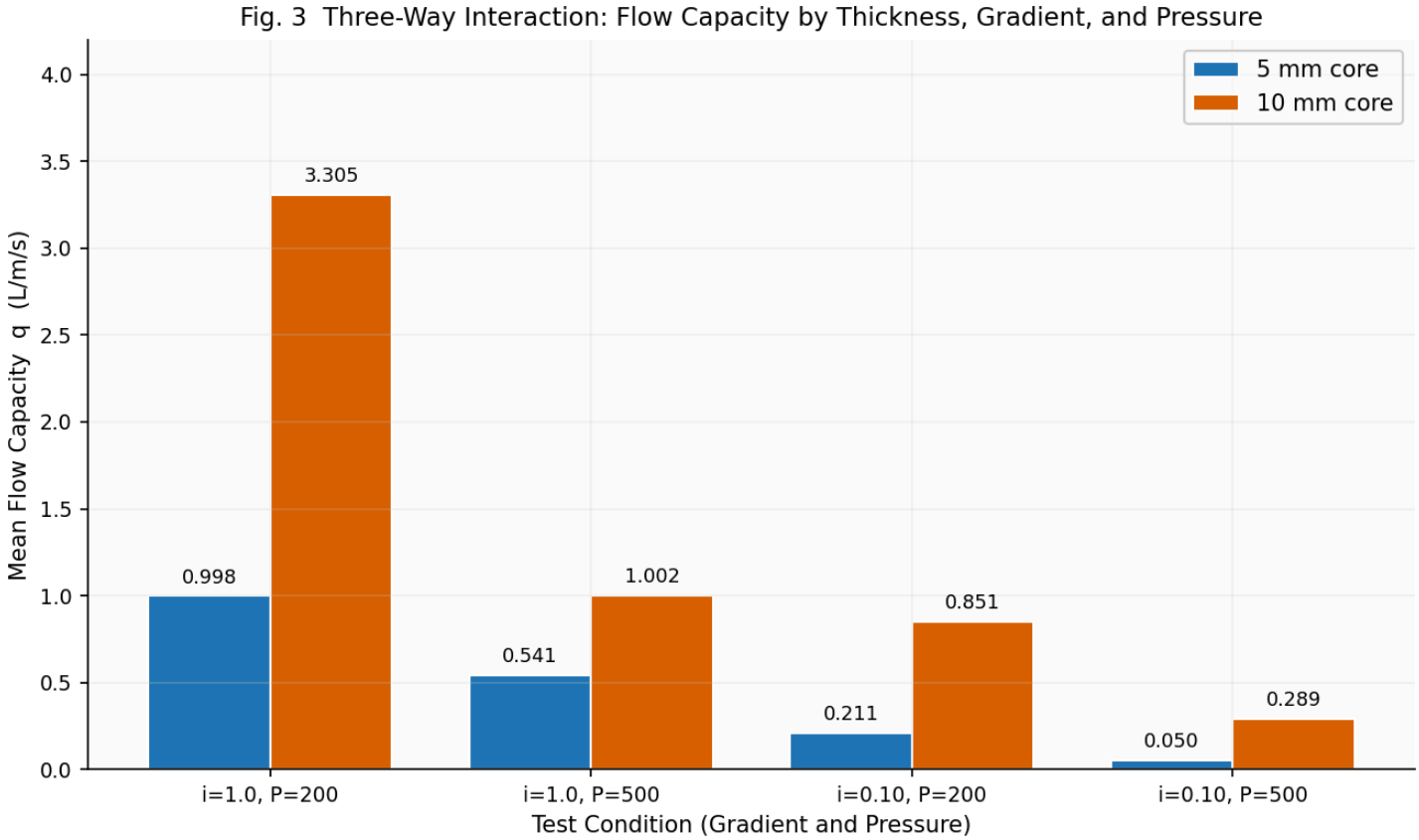


Figure 5

Mean flow capacity for 5 mm and 10 mm cores across all gradient-pressure combinations. The 10 mm core at gradient 1.0 shows the largest absolute drop between 200 and 500 kPa (3.305 to 1.002 L/m/s, a 3.3× reduction), while the 5 mm core at gradient 1.0 is less pressure-sensitive.