English Title: Framework for an Integrated Hydrogel-Enhanced Permeable Pavement System for Urban Flood Prevention on Sloped Roads in Stavanger

Norsk Tittel: Rammeverk for et Integrert Hydrogel-Forbedret Permeabelt Fortaussystem for Urban Flomforebygging på Skrånende Veier i Stavanger

By Kasun Siriwardane 07.02.25

1. Abstract

Urban flooding in Stavanger, Norway, presents a significant challenge due to its high rainfall and slanted terrain, which exacerbates stormwater runoff and overwhelms drainage systems. This study explores an innovative hydrogel-enhanced permeable pavement system to mitigate urban flooding, particularly on inclined roads. By integrating biodegradable hydrogels within permeable pavement layers, this system improves water retention, reduces runoff, and enhances infiltration rates while maintaining structural integrity. Experimental results indicate that hydrogel-enhanced pavements retain up to 30% more water than conventional permeable pavements and reduce surface runoff by approximately 25%. However, a trade-off between permeability and load-bearing capacity was observed, necessitating careful material selection and design optimization. A case study on Stiftelsesgata evaluates real-world feasibility, proposing an optimized pavement layout to balance coverage, cost, and efficiency. This research highlights the potential of hydrogel-integrated drainage solutions for sustainable urban development while identifying areas for further study on durability and maintenance.

2. Acknowledgements

I would like to thank Ms. Grace Goodwin for her feedback in shaping this paper and for helping to secure the several necessary equipment. I also acknowledge Ajay Kumar Saravana Kumar, a classmate and peer, who contributed early to this project by helping refine the study's scope and suggesting a funnel mechanism for real-world deployment. Although he later stepped away due, the remainder of the idea and work remains my own.

3. Introduction

Urban flooding occurring when heavy rainfall overwhelms drainage systems, causing disruptions, infrastructure damage, and environmental harm has become a global issue. This issue is especially. This issue is particularly severe in Stavanger, Norway, where widespread impermeable surfaces like asphalt and concrete prevent infiltration, increasing runoff and straining drainage capacity.

Stavanger’s coastal location and frequent rainfall necessitate sustainable flood mitigation solutions. Permeable pavements, designed for full, partial, or no infiltration (Fig. 1), help reduce runoff by allowing water absorption into an open-graded base. However, their effectiveness on slanted roads remains underexplored. This study investigates hydrogel-enhanced permeable pavements, where hydrogels—water-absorbing materials placed between pavement layers—improve retention and slow water flow.

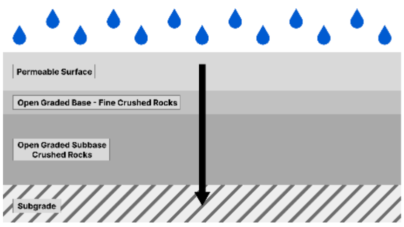

Fig. 1a: Full Infiltration System

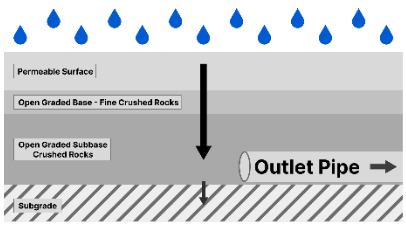

Fig. 1b: Full Infiltration System

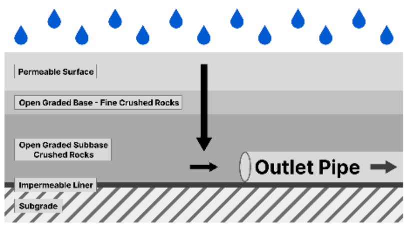

Fig. 1c: Full Infiltration System

To evaluate functionality and feasibility, this research compares the water management performance and structural strength of impermeable and permeable pavements through load testing. The main research question is: *How can an integrated hydrogel permeable pavement system reduce stormwater runoff and enhance flood prevention in Stavanger, particularly on slanted roads?* Findings will inform optimized pavement designs for Stavanger and other flood-prone urban areas.

4. Literature Review

Urban flooding, intensified by urbanization, climate change, and impermeable surfaces, poses a major challenge for coastal cities like Stavanger, which faces rising sea levels, extreme weather, and limited drainage capacity (Jiang, Zevenbergen, & Fu, 2017). With an annual rainfall of ~1800 mm and frequent autumn and winter storms (Yr.no, 2025), the city’s drainage systems often fail to handle intense rainfall, resulting in severe runoff and localized flooding. To address these issues, Stavanger has implemented sustainable drainage systems (SuDS) and nature-based solutions, such as Mosvatnet Park's water retention system and localized stormwater management in Gamle Stavanger (CityBlues Project Manager, 2024; Planke, 2023). However, increasing urbanization necessitates further innovative flood mitigation strategies tailored to the city's specific climatic conditions.

Stavanger’s sloped terrain intensifies stormwater runoff, increasing flood risk at lower elevations. Traditional permeable pavements—porous asphalt, pervious concrete, and permeable pavers—are designed for flat or slightly sloped surfaces (max 5% slope) to prevent erosion and material shifting. On sloped roads, reduced retention and uneven infiltration

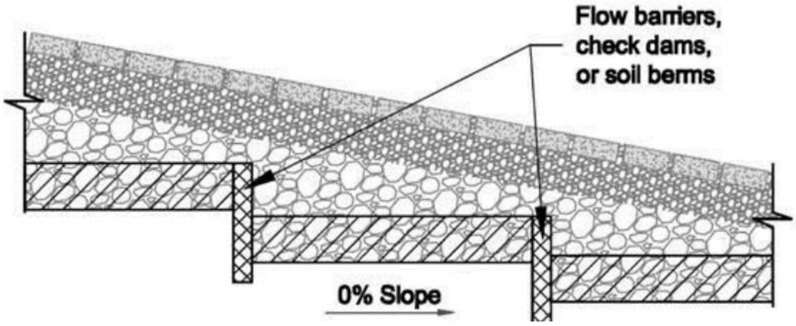

Fig. 2: The use of Flow Barriers on a Sloped Road (Department of Energy and Environment, 2024)

compromise drainage efficiency. Innovative solutions, such as terraced systems with internal flow barriers or check dams, can improve infiltration and structural integrity (Department of Energy and Environment, 2024).

Conventional stormwater infrastructure often fails under extreme rainfall, highlighting the need for adaptive alternatives (Richards & Edwards, 2018). Sustainable drainage systems, such as permeable pavements, enhance infiltration and reduce runoff, proving effective in groundwater recharge and peak flow management (Green et al., 2021). Adapted designs improve functionality in diverse urban environments (Larsen et al., 2016).

Hydrogels, widely used in agriculture and biomedical applications, offer high water retention but remain underexplored in urban drainage systems. Biodegradable biopolymer hydrogels significantly enhance water retention while maintaining environmental sustainability (Skrzypczak et al., 2020). Studies show hydrogels can improve water retention by up to 2,000%, suggesting that similar results in porous systems are possible, reducing runoff and flood risks (Al-Mahbashi & Almajed, 2024). However, their long-term durability, maintenance, and cost require further study before large-scale adoption.

Permeable pavements filter pollutants, improving water quality and protecting aquatic ecosystems. By reducing surface temperatures, they mitigate urban heat island effects and support climate adaptation. Additionally porous pavements amplify these benefits by preventing ice formation on roads, beneficial for inclined roads (Xie, Akin & Shi, 2018).

4.1. Knowledge Gaps and Experimental Justification

The integration of hydrogels in permeable pavements has never been applied nor theorized, making this study the first to explore their potential for urban stormwater management. While hydrogels are widely studied in agriculture and biomedical fields, their ability to enhance water retention, infiltration, and flood mitigation in pavement systems remains unexamined.

Additionally, although sloped roads have been investigated, research remains limited as most permeable pavement designs are optimized for flat surfaces. Steeper gradients accelerate runoff, reduce infiltration time, and pose structural challenges, making their application in flood-prone areas like Stavanger particularly demanding. This study aims to evaluate the feasibility of hydrogel-enhanced permeable pavements, addressing both the knowledge gaps: the potential of hydrogels and the critical need for more effective flood solutions on sloped urban roads.

5. Experimental Design

This study evaluates the performance of three pavement systems—conventional impermeable pavement, permeable pavement without hydrogel, and permeable pavement with a hydrogel base—to address urban stormwater management challenges. The experiment systematically assesses their infiltration rate, water retention capacity, surface runoff volume, and structural strength under simulated rainfall conditions.

The study investigates the following hypotheses:

Hypothesis	Rationale
H1: Permeable pavements reduce surface runoff and increase water retention compared to impermeable surfaces.	Permeable pavements facilitate water infiltration, reducing runoff and peak stormwater loads. Impermeable pavements lead to pooling, erosion, and drainage system overload.
H2: The addition of a hydrogel layer improves water retention by slowing the infiltration rate.	Hydrogels absorb and gradually release water, controlling stormwater flow and reducing peak discharge into drainage systems.
H3: Increased debris accumulation lowers infiltration rates.	Debris clogs pavement pores, decreasing permeability and leading to higher surface runoff, similar to conventional impermeable pavements.

This experiment incorporates two independent variables (IVs) and three dependent variables (DVs), as summarized in Table 1.

Table 1: Independent and Dependent Variables

<table>
<tr><th>Type</th><th>Variable</th><th>Description</th><th>Range of Values / Measurement</th></tr>
<tr><td rowspan="2">IV</td><td>Pavement Type</td><td>Different pavement configurations tested.</td><td>1. Impermeable Pavement (Control) – (1 part cement, 2 parts sand and 3 parts aggregate)
2. Permeable Pavement – (1 part cement and 5 parts aggregate)
3. Permeable pavement with hydrogel – (1 part cement, 5 parts aggregate, and Hydrogel layer)</td></tr>
<tr><td>Debris</td><td>Simulated urban debris affecting permeability.</td><td>0 ml, 5 ml, 10 ml, 15 ml, 20 ml</td></tr>
</table>

			The unit is ml as this is a compressed mix of leaves, dirt and grass spread uniformly.
DV	Infiltration Rate (cm/s)	Speed at which water infiltrates through the pavement.	$I = \frac{V}{T \times A}$, where V is volume of infiltrated water (cm^3), T is infiltration time (s), and A is pavement surface area (cm^2).
	Water Retention Rate (cm^3/s)	Rate at which water is retained within the system.	$R = \frac{V_{retained}}{T_{max}}$, where $V_{retained}$ is volume of retained water (cm^3) and T_{max} is time taken to reach maximum retention.
	Surface Runoff (cm^3)	Volume of water that does not infiltrate and runs off the pavement.	Measured using cross-verified ImageJ analysis, through known reference lengths.

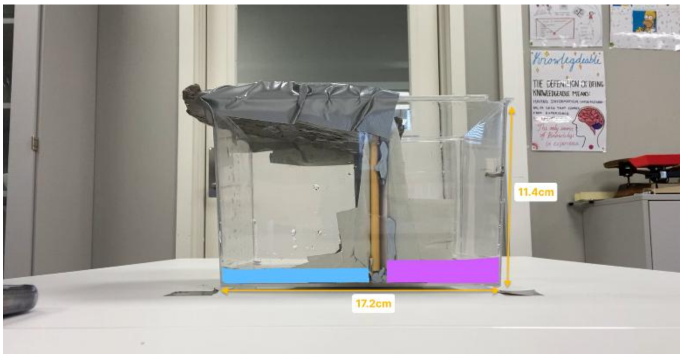

Fig. 3: Image J analysis and cross-verification of error margins using known references

To ensure consistency and reliability, key control variables were standardized. Rainfall conditions were maintained with a 200 ml water volume and 50 mm/hour intensity to replicate heavy downpours, while water properties were kept at pH 7 and 20°C. Pavement conditions were controlled by setting a fixed slope of 15°, standardizing sample dimensions (11.5 cm × 13 cm × 2 cm), and using precise cement-to-aggregate ratios for impermeable and permeable pavements. Environmental factors such as room temperature (22°C) and identical frustum-shaped testing containers were kept constant to prevent variability. All measurement tools and equipment remained the same across the three trials to ensure accuracy in infiltration, retention, and runoff assessments. The experimental design setup can be seen in figures 4**.**

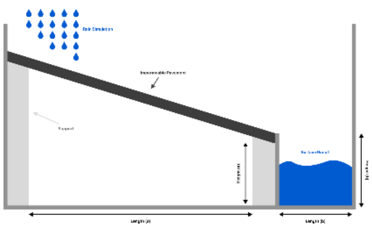

Fig. 4a: Impermeable Pavement

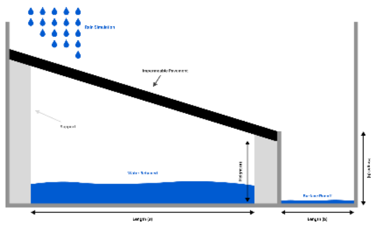

Fig. 4b: Permeable Pavement

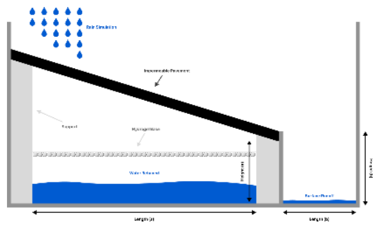

Fig. 1c: Permeable with Hydrogel

For the load-bearing test, incremental weights were applied until the pavement fractured, measuring the maximum load before failure (kg) to assess the trade-off between permeability and structural strength. Additionally, to ensure safety and accuracy, PPE (gloves, goggles, masks) was used to prevent exposure to concrete powder. Water was reused across multiple trials to reduce waste, and all equipment was cleaned and reused for consistency. Measurements were recorded under identical conditions using calibrated tools to maintain data integrity.

The experiment systematically evaluates hydrogel-enhanced permeable pavements using controlled rainfall simulations, infiltration and retention measurements, surface runoff analysis, and load-bearing tests. The findings will inform optimized pavement designs for urban flood prevention.

6. Results

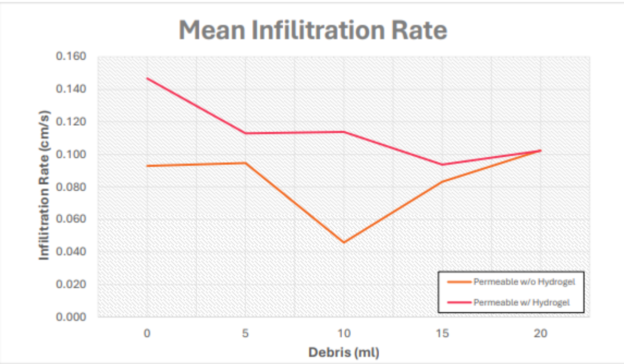

Fig. 5: Permeable Systems Mean Infiltration Rate vs Debris

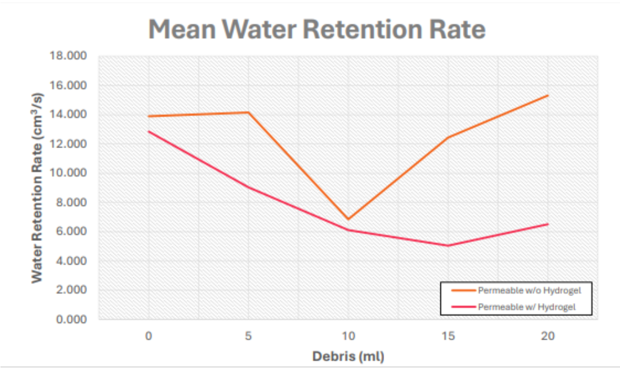

Fig. 6: Permeable Systems Mean Water Retention Rate vs Debris

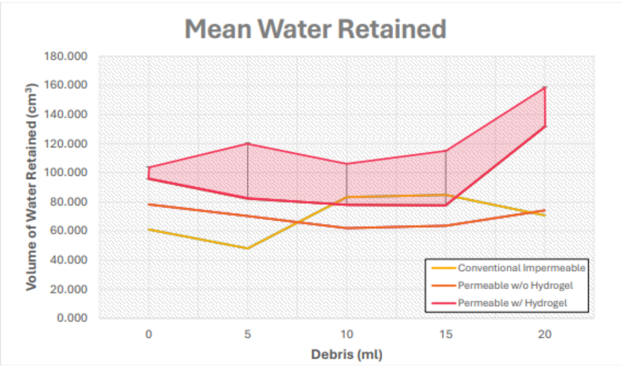

Fig. 7: Pavement Types Mean Water Retained vs Debris

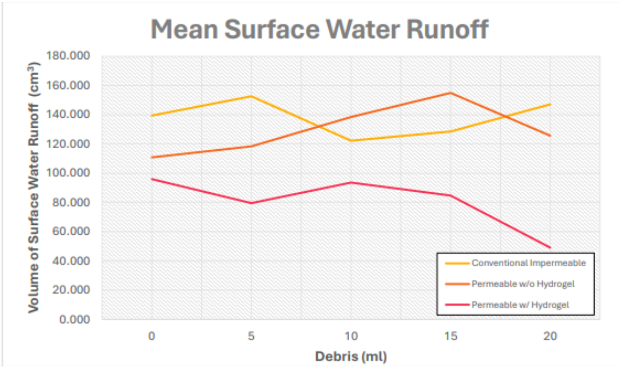

Fig. 8: Pavement Types Mean Water Runoff vs Debris

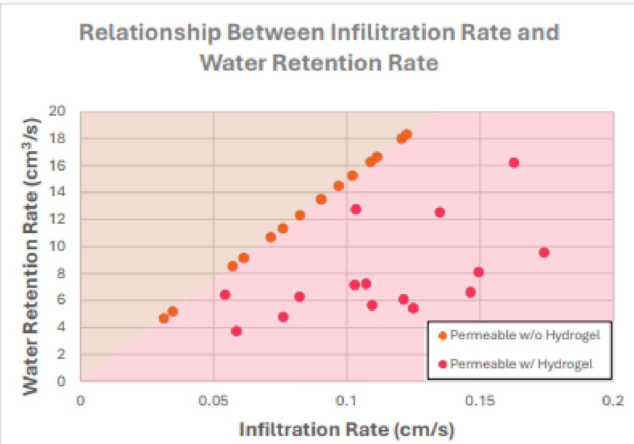

Fig. 9: Relationship between infiltration rate and water retention rate

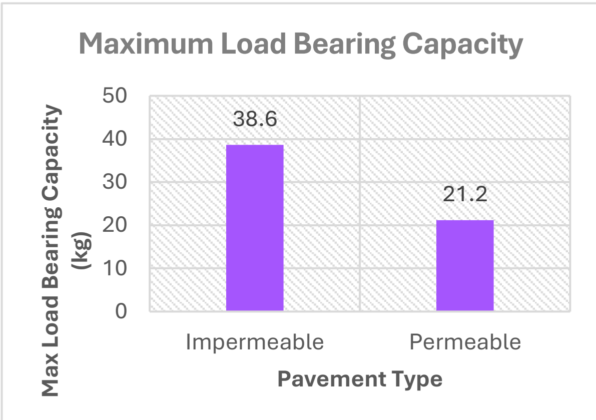

Fig. 10: Pavement Types Maximum Load Bearing Capacity

The graphs illustrate key trends in pavement performance under varying conditions. Figure 5 shows declining infiltration rates as debris increases, while Figure 6 highlights improved water retention with hydrogel integration. Figure 7 confirms that hydrogel-enhanced pavements retain more water, whereas Figure 8 demonstrates that impermeable pavements produce significantly higher runoff. Figure 9 reveals a negative correlation between infiltration rate and retention, supporting hydrogel effectiveness, and Figure 10 compares load-bearing capacities, showing impermeable pavements withstand higher loads but lack water management benefits.

7. Discussion and Interpretations

7.1. Limitations of the Method

While minor inconsistencies in pavement construction, limited trials (3), and potential variability in debris application may have influenced results, the study's strengths outweigh these limitations. A systematic approach, controlled variables, and precise measurements ensured reliability, while ImageJ analysis enhanced accuracy. Increasing trial replication and refining construction techniques could further improve future research.

7.2. Analysis of Key Findings

The infiltration rates for pavements with and without hydrogel were expected to be similar, as hydrogel is placed below the surface and does not directly influence permeability. However, results indicate an initial discrepancy, with hydrogel-enhanced pavements exhibiting a higher infiltration rate at 0 ml of debris (0.145 cm/s vs. 0.095 cm/s for non-hydrogel pavements). This could be due to minor variations in pavement construction and the hydrogel's effect on structural stability, preventing surface clogging. As debris levels increased, infiltration rates converged, stabilizing at 0.102 cm/s for both pavements at 20 ml of debris. This suggests that hydrogels contribute to maintaining permeability under debris accumulation.

Water retention analysis further highlights hydrogel's effectiveness in controlling stormwater flow. A lower retention rate indicates slower water release, reducing flood risk. At 10 ml of debris, the hydrogel-enhanced pavement exhibited a retention rate of 6 cm^3/s, compared to 10 cm^3/s for the non-hydrogel pavement. Even at 20 ml, the hydrogel system outperformed, maintaining a retention rate of 7 cm^3/s, while the standard permeable pavement increased to 16 cm^3/s. This confirms that hydrogels improve water retention and prevent rapid drainage.

The relationship between infiltration and retention is further supported by Figure 9, where hydrogel pavements deviate down from the expected linear relationship, demonstrating their ability to slow water flow despite higher infiltration rates.

The load-bearing test revealed a trade-off between permeability and structural strength. The impermeable pavement supported a maximum load of 38.6 kg, whereas the permeable pavement, with its porous structure, had a lower capacity of 21.2 kg. While hydrogel enhances water retention, further material optimization is needed to ensure strength without compromising permeability.

Overall, hydrogel-enhanced pavements significantly reduce surface runoff, stabilize infiltration under debris, and improve retention, making them a viable solution for urban flood management. However, routine maintenance is essential to prevent clogging and maintain effectiveness over time.

7.3. Evaluation of Hypotheses

H1: The results strongly support this hypothesis. At 0 ml of debris, hydrogel-enhanced pavements retained 95.8 ml of water, significantly more than 78.2 ml for standard permeable pavements and far exceeding impermeable pavements. Runoff analysis also confirms this trend, with hydrogel pavements consistently reducing runoff by approximately 25% compared to impermeable systems.

H2: This hypothesis is validated by the hydrogel-enhanced pavement's slower water retention rates across all debris levels. At 15 ml of debris, the hydrogel system retained water at 5.0 cm^3/s, compared to 12.4 cm^3/s for standard permeable pavements. This demonstrates hydrogel’s capacity to absorb and gradually release water, preventing sudden drainage system overload.

H3: The data strongly supports this hypothesis, showing a decline in infiltration rates with increasing debris. The hydrogel-enhanced pavement's infiltration rate dropped from 0.147 cm/s at 0 ml to 0.102 cm/s at 20 ml, while the standard permeable pavement fell from 0.093 cm/s to 0.046 cm/s. Despite this decline, the hydrogel-enhanced pavement exhibited greater stability, suggesting a secondary benefit of hydrogel in maintaining functionality under debris accumulation.

The findings confirm that hydrogel integration enhances permeable pavement performance by improving water retention and reducing runoff, particularly under high-debris conditions. However, structural trade-offs must be addressed to balance strength and permeability for practical urban applications.

7.4. Broader Implications

The study highlights the potential of hydrogel-enhanced pavements to address urban flooding challenges through improved infiltration, retention, and runoff management. These systems are particularly suited for cities like Stavanger, where frequent rainfall and rising sea levels demand innovative solutions. The findings set the stage for the next section, which explores the feasibility of implementing these pavements in Stavanger's urban infrastructure.

8. Case Study: Urban Stavanger

8.1. Site Selection

This case study applies the findings of hydrogel-enhanced permeable pavement systems to a flood-prone area in Stavanger exacerbated by heavy rainfall, to evaluate the system's feasibility and impact. The selected site, Stiftelsesgata, spans approximately 307 metres, 8 metres wide and is in central urban Stavanger. This area among others is prone to frequent water pooling and drainage overflows due to the dense buildings although located near a lake. Stiftelsesgata was chosen due to its impermeable surface, derived angle of depression of 4°, and surrounding green area implying easy pavement renovation and possibilities of a partial-full infiltration system. Its proximity to religious places of worship, schools and residential zones underscores the urgency of implementing effective flood mitigation solutions.

8.2. Permeable Pavement Design

The cross-section of the proposed hydrogel-enhanced permeable pavement system consists of multiple layers designed to optimize water infiltration and retention while ensuring structural stability. At the top, a permeable pavement surface material allows rainwater to pass through, reducing surface runoff. Beneath it, a bedding layer provides support and enhances load distribution. A key innovation in this design is the hydrogel layer confined by a steel mesh, which absorbs and slowly releases water, improving flood mitigation and maintaining pavement integrity. Below this, an open-graded subbase reservoir layer stores excess water, facilitating gradual infiltration into the subgrade, which interacts with the natural soil. Additionally, an outlet pipe allows the enablement of a partial-full system. This multi-layered approach enhances permeability, prevents drainage overflows, and supports urban flood resilience in Stavanger's sloped terrain.

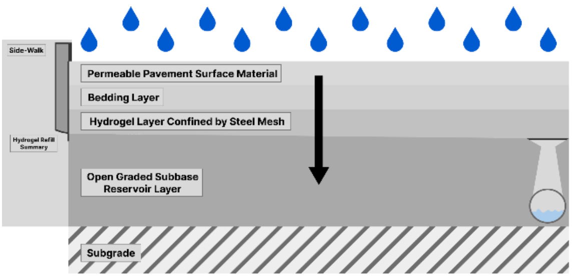

Fig. 11: Cross Section Proposed Pavement System

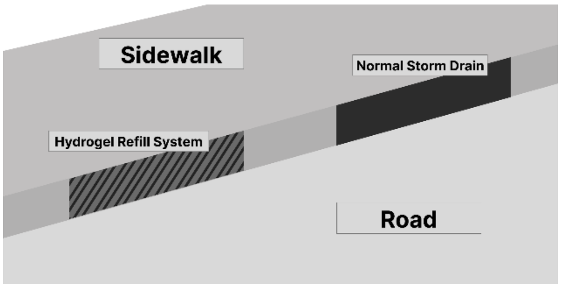

Fig. 12: Hydrogel Refill System on Sidewalk

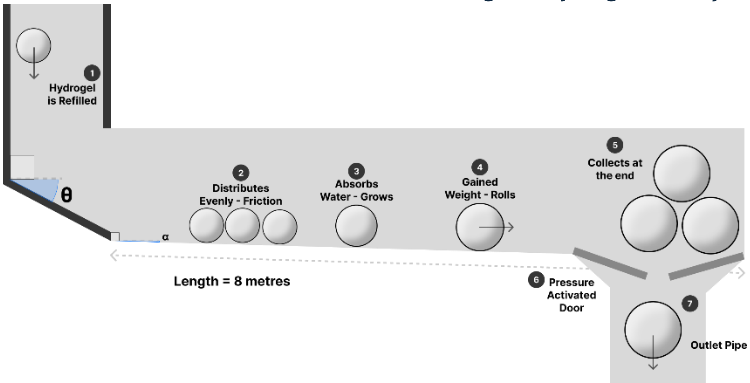

Fig. 13: Proposed Hydrogel Layer Flowchart

A critical component of this system is the hydrogel layer, where small hydrogel balls are introduced via a vertical pipe and guided by a tilted surface at angle θ. This ensures an even spread into the steel-mesh-confined layer, preventing excessive accumulation at one end. The angle θ must be optimized to balance sufficient rolling motion for entry while preventing excessive velocity that could lead to uneven distribution. Using kinematic equations, the velocity of a hydrogel ball at the end of the inclined surface is determined by:

$$v_f = \sqrt{\frac{10}{7} g d \sin\theta}$$

where g is gravitational acceleration, and d is the surface length. To prevent clustering, the horizontal velocity component must remain moderate:

$$v_{horizontal} = v_f \cos\theta$$

suggesting that θ should ideally fall within the $15° - 45°$ range. Further along, the hydrogel balls enter the hydration phase, resting on a second surface inclined at angle α, where they absorb water and expand before rolling into the collection area. This angle must be small enough to prevent premature movement but large enough to induce rolling as the balls increase in size. The static equilibrium condition dictates that rolling will not occur if:

$$\tan\alpha \leq \mu_s$$

where μ_s is the coefficient of static friction. Conversely, once the hydrogel balls grow sufficiently, their weight increases, eventually overcoming static friction, and rolling begins when:

$$\tan \alpha \leq \mu_s$$

To ensure an optimal transition, α should be set just above the critical friction threshold:

$$\alpha_{optimal} = \arctan \mu_s + \epsilon$$

where ϵ is a small buffer angle to account for growth-induced rolling. In most practical scenarios, α should range between 5° and 15°, ensuring that small balls remain stationary while larger, fully hydrated balls begin rolling at the right stage. This careful control of both θ and α optimizes hydrogel distribution, absorption, and movement, ensuring efficient system performance.

The hydrogel-enhanced pavement system requires precise layering for durability and optimal drainage. The permeable surface ensures infiltration, while the bedding layer supports load distribution. The hydrogel layer, confined by steel mesh, must be evenly placed to prevent displacement. Proper drainage connections link the hydrogel to the subbase reservoir, allowing controlled water flow. A strategic outlet pipe manages overflow, ensuring adaptability to varying water levels.

This system can enhance urban drainage by reducing surface runoff and preventing localized flooding. Placed in flood-prone areas, the hydrogel layer absorbs excess rainwater, easing pressure on storm drains. The outlet pipe connects to drainage channels, allowing controlled release. Integration with existing infrastructure supports water retention, erosion control, and long-term urban resilience.

8.3. Mathematical and Computational Optimization for Sloped Roads

To optimize the hydrogel-enhanced permeable pavement system on Stiftelsesgata, we modeled the triangular road profile as a constraint for identical, non-overlapping rectangular reservoirs. These rectangles must have one vertex on the hypotenuse, total an area of at least 80 m^2, and span a combined width of at most 305 m. The optimization problem is governed by: 1) Coverage Constraint: $n \times w \leq 305$; 2) Area Constraint: $n \times w \times h \geq 80$; 3) Cost Function: $C = n \times w \times h \times,\ c \in [500, 1345]\, NOK/m^2$, where n is the number of reservoirs, w is the width of each rectangle, h is the height of each rectangle, C is the total cost and c represents cost per square meter.

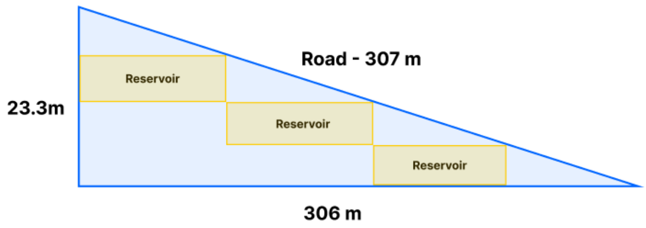

Fig. 14: Optimization Problem - Find optimal reservoir count and size

A computational grid search systematically evaluated feasible (n, w, h) configurations, ranking solutions by maximum coverage → lowest cost → minimum rectangles. The best solutions (shown above) all met the constraints, achieving 305 m coverage, with areas ranging from 457.5 to 488 m^2 and costs between 228,750 to 656,360 NOK.

Table 2: Python Optimized Top 5 Solutions

SN	Solution Details
1	$N = 2, Width = 152.5\,m, Height = 1.5\,m, Coverage = 305, Area = 457.5\,m^2$, $Cost_{min} = 228750\,NOK$, and $Cost_{max} = 615337.5\,NOK$
2	$N = 25, Width = 12.2\,m, Height = 1.5\,m, Coverage = 305, Area = 457.5\,m^2$, $Cost_{min} = 228750\,NOK$, and $Cost_{max} = 615337.5\,NOK$
3	$N = 25, Width = 12.2\,m, Height = 1.5\,m, Coverage = 305, Area = 457.5\,m^2$, $Cost_{min} = 228750\,NOK$, and $Cost_{max} = 615337.5\,NOK$
4	$N = 61, Width = 5\,m, Height = 1.5\,m, Coverage = 305, Area = 457.5\,m^2$, $Cost_{min} = 228750\,NOK$, and $Cost_{max} = 615337.5\,NOK$
5	$N = 2, Width = 152.5\,m, Height = 1.5\,m, Coverage = 305, Area = 488\,m^2$, $Cost_{min} = 24400\,NOK$, and $Cost_{max} = 656360\,NOK$

Among these, Solution 2 is the most balanced. Its medium amount of reservoirs help even collection of water while simplifying installation, and maximizes flood retention. With a minimum reservoir height of 1.5 m, its volume ($457.5m^2 \times 8m = 3660\,m^3$) exceeds the annual rainfall amount. Thus, Solution 2 is recommended for effective flood mitigation in Stavanger.

8.4. Performance Evaluation Framework

To assess the effectiveness of the hydrogel-enhanced permeable pavement system, several key performance metrics will be monitored, including infiltration rate, water retention efficiency, reduction in surface runoff, and structural integrity over time. Sensors embedded within the system will measure real-time water absorption and release rates, ensuring optimal hydrogel performance.

Regular maintenance checks will also be conducted to inspect hydrogel layer integrity, drainage function, and load-bearing capacity. Comparative analysis with conventional impermeable pavements in adjacent areas will provide insights into the system's long-term benefits, including reduced flooding incidents and improved urban resilience. User feedback from residents and local authorities will be incorporated to evaluate practicality and potential improvements.

8.5. Cost-Benefit Analysis and Environmental and Social Impacts

Implementing hydrogel-enhanced permeable pavements requires an initial investment in specialized materials, including hydrogels, steel mesh reinforcements, and modified pavement layers, with costs ranging from 500–1345 NOK/m^3 depending on hydrogel type and structural modifications, due to the variety of organizations and commercial stores that offer different prices. While traditional impermeable pavements are slightly cheaper per cubic meter (rough minimum cost of 450 NOK/m^2), they lack flood mitigation benefits, leading to higher long-term expenditures for stormwater management, drainage repairs, and urban flood damage. The hydrogel system offsets these costs by reducing peak runoff, easing pressure on drainage infrastructure, and minimizing emergency flood response and maintenance. Environmentally, it improves water quality by filtering pollutants before they enter nearby lakes and rivers, reduces the urban heat island effect, and enhances groundwater recharge. Socially, its application in flood-prone areas like Stiftelsesgata improves pedestrian safety, prevents waterlogging, and increases accessibility for vulnerable groups, including children, the elderly, and individuals with disabilities. Its strategic placement near schools and residential zones promotes safer mobility and strengthens urban resilience against extreme rainfall.

8.6. Challenges and Limitations

Despite its numerous advantages, the hydrogel-enhanced permeable pavement system faces several challenges. Material costs remain higher than traditional pavements, requiring careful budget planning to ensure economic feasibility. Additionally, hydrogel degradation over time necessitates periodic replenishment, introducing long-term maintenance costs. Engineering constraints related to load-bearing capacity must be addressed to ensure structural stability in high-traffic zones. Moreover, while the system is designed for flood-prone areas, its efficiency may vary with seasonal rainfall fluctuations, requiring continuous monitoring and adaptive management. Engaging local communities and urban planners will be essential to ensure long-term acceptance and sustainability.

8.7. Scaling and Replications

The findings from the Stiftelsesgata case study can be replicated in other flood-prone urban areas in Stavanger and similar cities experiencing intense rainfall and drainage challenges. By adapting the system's design parameters—such as hydrogel quantity, subbase thickness, and drainage configurations—to different road slopes and soil conditions, the technology can be customized for various terrains. In regions with steeper gradients, flow barriers may be integrated to slow water movement and enhance infiltration. The success of this case study could pave the way for broader collaborations between urban developers, environmental agencies, and municipal governments, leading to widespread adoption of hydrogel-enhanced pavements as a standardized flood mitigation strategy in urban planning.

9. Conclusion

This study demonstrates that hydrogel-enhanced permeable pavements significantly improve water infiltration and retention, making them a viable solution for mitigating urban flooding in Stavanger, particularly on sloped roads. By integrating biodegradable hydrogels within pavement structures, this system effectively reduces runoff while enhancing stormwater management, offering a promising alternative to traditional impermeable surfaces. Experimental findings confirm the hydrogels' ability to absorb and gradually release water, reducing peak flows and easing pressure on drainage infrastructure. However, challenges related to structural strength, material longevity, and maintenance requirements must be addressed before large-scale implementation. Future research should focus on optimizing hydrogel composition and evaluating long-term and large-scale performance under real-world traffic conditions to ensure both functionality and durability.

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