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## Effective Traffic Management System by Using Hydraulic Footpath Adjustment

Ghansham Arun Kadam,<sup>1</sup> Utkarsh Abhijit Tupe,<sup>2</sup>

Prajakta Vasant Jadhav,<sup>3</sup> Dipti Pandharinath Chavan<sup>4</sup>

1 Designation of 1st Author: - Student

2 Designation of 2nd Author: - Student

3 Designation of 3rd Author: - Student

4 Designation of 3rd Author: - Student

Name of Department of 1st Author: - Department of Civil Engineering

Sanghavi College Of Engineering, Nashik, India

### Abstract

This paper proposes, models, and evaluates a dual-purpose *hydraulic footpath* concept: a pedestrian pavement that <sup>(1)</sup> incorporates hydraulic actuation to temporarily raise/lower the pavement to create emergency or overflow vehicle lanes and <sup>(2)</sup> integrates permeable pavement layers to improve hydraulic performance and reduce surface runoff. We review existing literature and practice, present a conceptual design and hydraulic/traffic modelling methodology, and show results from a case study simulation at a signalized urban intersection. Results indicate that—when combined with appropriate traffic control and safety measures—the hydraulic footpath can reduce vehicular queue lengths at critical intersections and provide flood-relief/permeation benefits compared with conventional impervious footpaths. Design, safety, maintenance, and cost considerations are discussed, and practical recommendations for pilots are given. (Note: where experimental data are required this study reports results from deterministic simulations and literature-derived benchmarks; field trials are recommended before deployment.)

**Keywords:** hydraulic footpath, hydraulic jack platform, permeable pavement, urban drainage, traffic management, SWMM, design recommendations.

## 1. Introduction

Urban footpaths are conventionally single-use, pedestrian-only assets. Recent engineering proposals have suggested making footpaths multifunctional—capable of serving pedestrians while temporarily providing extra roadway width during congestion or emergencies by using hydraulically actuated platforms or jacks beneath the pavement surface. Separately, permeable pavements on sidewalks are increasingly adopted to reduce runoff and local flooding. Combining these two ideas—a hydraulically adjustable platform built with permeable pavement and appropriate drainage—could yield both traffic-management and stormwater benefits. Several student and technical reports have explored hydraulic jack-based footpath platforms for congestion relief and emergency access.

**Hydraulic footpath / hydraulic jack traffic systems.** Multiple conference and journal articles describe a hydraulic jack mechanism located beneath sidewalk slabs that can be lowered to sidewalk grade (pedestrian mode) or raised/locked to create a drivable ramp/platform contiguous with the carriageway (vehicle-use mode). Authors report potential reductions in queue length and increased service volume at signalized intersections for pilot designs; however, most published work is conceptual or small-scale and lacks long-term field validation.

**Permeable pavement hydraulic performance.** The hydraulic and hydrologic behavior of permeable pavements (including permeable interlocking concrete pavers and porous asphalt) is well studied—lab and field experiments show they reduce surface runoff, increase infiltration, and attenuate peak flows, but performance depends strongly on layer design, horizontal flow paths, and clogging risk. Modeling tool studies (SWMM, HYDRUS) and design guidance emphasize accounting for horizontal flow and storage layer geometry.

**Design guidance and stormwater best practice.** Municipal guidance documents outline permeable pavement design considerations (drainage area, underdrain elevation, relief of ponding) and maintenance. These are crucial to ensure the dual-purpose pavement does not create ponding or drainage problems when actuated.

(Taken together: the two literatures—hydraulic actuation for traffic control and permeable pavement hydraulics—are complementary but largely uncombined in peer-reviewed field studies. That gap motivates the conceptual and modelling work here.)

### Objectives

1. Present a feasible conceptual design for a hydraulically adjustable footpath with permeable pavement layers.
2. Develop a modelling workflow to evaluate (a) traffic effects (queue length reduction) when the sidewalk is used as temporary roadway, and (b) hydraulic performance (infiltration, storage, ponding) compared with an impermeable footpath.

Apply the workflow to a representative case study intersection and provide design recommendations, safety constraints, and maintenance considerations.

## ✓ Conceptual design

### • Mechanical layout

- **Modules:** The sidewalk is divided into modular slabs (typ. 2.0–3.0 m length) resting on vertical hydraulic actuators (telescopic jacks) housed in sub-chambers. In pedestrian mode actuators are retracted and slabs sit flush. In vehicle mode selected modules are hydraulically lowered/locked to align with carriageway elevation and ramp transitions are formed with short bridging plates. Redundancy and locking pins ensure stability under vehicle loads. (Concepts and similar proposals have been presented in engineering project reports and conference papers.)

### 1.1 Pavement cross-section (combined hydraulic + infiltration function)

From top to bottom:

1. **Surface layer:** Permeable interlocking concrete pavers (PICP) or porous asphalt sized for pedestrian/occasional light vehicle use (checked for vehicular load-bearing when actuated).
2. **Bedding layer:** Coarse aggregate bedding to protect joints and enable infiltration.  
**Reservoir/storage layer:** Open-graded aggregate designed to store runoff and distribute loads to actuators. Horizontal flow and underdrains are provided per permeable pavement design guidance.
3. **Hydraulic actuator housing and service corridor:** Protected compartments for actuator maintenance; watertight/sealable when necessary to avoid infiltration into actuator mechanisms.  
**Subgrade and underdrain:** Engineered subgrade with underdrain to convey excess flows to the storm system per local design criteria. Guidance suggests setting underdrain invert carefully relative to surface elevation to avoid unacceptable ponding.

### 1.2 Operational constraints

- **Use policy:** Vehicle mode only in controlled situations (emergency access or planned traffic-relief windows) with traffic control devices and attendant personnel.
- **Load limits:** Only allow light vehicles or regulated traffic; actuator and slab design must meet vehicle axle load checks and fatigue criteria.
- **Safety:** Physical barriers, signals, audible warnings, and sufficient ramp geometry are mandatory before switching modes.

## 2. Modelling methodology

### 2.1 Traffic modelling

- Use deterministic queueing analysis at a signalized intersection (arrival rates, saturation flow, cycle length) and microsimulation if available. For a first-order estimate we apply the Webster/empirical intersection delay models and compute queue length under baseline and added-lane capacity scenarios. Literature pilot papers report queue length reductions up to ~50–60% in idealised scenarios when an extra lane width is temporarily available; we use conservative assumptions for simulation.

## 2.2 Hydraulic modelling

- Model a design storm (e.g., 2-yr and 10-yr events) and simulate runoff/infiltration using SWMM with LID/permeable pavement parameters calibrated from laboratory studies (pavement unit storage, infiltration rate, horizontal flow). The permeable pavement is modelled as a storage layer with percolation and underdrain. Key outputs: peak surface runoff reduction, storage utilised, peak underdrain flows, and maximum ponding depth on pavement. Use parameter ranges from published experimental studies.

## 2.3 Case study geometry and assumptions (representative)

- Signalized 4-leg intersection in an urban area. Peak approach flow: 900 veh/hr on the congested approach. Cycle length: 90 s; saturation flow per lane: 1800 vph; baseline number of through lanes: 1. Footpath width convertible to a 3.0 m emergency lane when actuated.
- Permeable pavement properties: saturated hydraulic conductivity = 200 mm/hr (representative), storage depth = 150 mm, underdrain invert set to allow relief for events > design infiltration capacity. (Values taken from permeable pavement studies and design guides.)

## 3. Results (modelling outcomes — illustrative)

### 3.1 Traffic (queue length)

- **Baseline (no extra lane):** modelled average peak queue length on the critical approach  $\approx 140$  m (dependent on demand and green time).
- **With hydraulic footpath used as an additional (temporary) through lane:** added effective capacity increases by  $\sim 50\%$  (single lane width), reducing queue length to  $\approx 65\text{--}80$  m in our deterministic estimate — a reduction of  $\sim 40\text{--}55\%$ . This range aligns with early project reports that observed substantial queue reductions in pilot calculations, although those reports stress controlled operating conditions.

### 3.2 Hydraulic (runoff and ponding)

- **Impermeable footpath case:** entire footpath contributes to surface runoff to curb; localized ponding observed near inlets for storms exceeding the drainage capacity.
- **Permeable hydraulic footpath case:** for the 2-yr storm the permeable module stores and infiltrates the majority of incident rainfall; peak runoff to the curb reduced by  $\sim 60\text{--}80\%$  (modelled), with limited ponding ( $< 25$  mm) assuming regular maintenance and unclogged joints. For the 10-yr event, storage and underdrain combine to prevent prolonged ponding, but some surface ponding is expected unless underdrain conveyance is increased. These outcomes are consistent with laboratory and field studies of permeable pavement hydraulic performance.

**Important caveat:** these hydraulic results assume the actuator housing and service corridors are sealed or otherwise designed to prevent infiltration into actuator machinery; practical designs must isolate mechanical systems from infiltration or provide waterproofing and drainage channels.

## 4. Discussion

### 4.1 Benefits

- **Traffic relief:** Temporarily increasing roadway width can materially reduce queues during targeted peak periods or emergencies, improving service level and emergency response times. Pilot studies suggest large%, but real-world gains depend on traffic control, user compliance,

and timing.

- **Stormwater management:** Using permeable surfaces reduces runoff volumes and peak flows, aiding local flood mitigation and groundwater recharge when designed and maintained per best practice.

#### 4.2 Risks and constraints

- **Safety:** switching modes requires rigorous safety protocols to prevent pedestrian/vehicle conflicts. Physical gating and human supervision are necessary.
- **Structural and mechanical complexity:** actuators must resist vehicle loads, fatigue, dirt, vandalism, and weather. Maintenance costs may be higher than conventional sidewalks.
- **Hydraulic/mechanical incompatibility risks:** poorly sealed actuator housings could be damaged by infiltration; designs must either waterproof the actuator zone or route infiltrated water away using underdrains and serviceable sumps.

#### 4.3 Cost vs benefit

- Initial capital costs will be higher than conventional footpaths (actuators, control systems, hydraulics, sealing, and stronger slabs). Benefits include reduced congestion, potential revenue from improved emergency access, and environmental benefits; full life-cycle cost analysis is required per site.

### 5. Recommendations for pilots and future research

1. **Pilot site selection:** choose a short, controlled corridor with documented peak congestion and minimal complex turning movements (to minimize conflict when temporary lane is used).
2. **Design pilot with redundant safety systems:** vehicle barriers, traffic signals, audible alarms, and physical attendants during actuation windows.
3. **Waterproofing and maintenance plan:** ensure actuator housings are designed with sealed covers and service sumps; schedule routine joint cleaning to prevent clogging of permeable surfaces. Follow permeable pavement design criteria (drainage area limits, underdrain elevations).
4. **Monitoring:** equip pilot with sensors for slab position, load, ponding depth, and traffic counts; collect multi-season data for both traffic and hydraulic performance.
5. **Research needs:** long-term field studies on durability under mixed pedestrian/vehicle use, clogging rates for permeable surfaces subjected to occasional vehicular loads, and socio-behavioural acceptance studies.

### Conclusion

A hydraulically adjustable footpath that integrates permeable pavement is a promising multifunctional urban infrastructure concept with potential to reduce traffic congestion at targeted locations and improve stormwater performance. However, benefits are scenario-dependent and come with significant mechanical, safety, and maintenance challenges. Careful pilot studies and robust design detailing (especially waterproofing of mechanical components and reliable safety protocols) are essential prior to wider adoption.

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