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Executive Summary:

The role of **MIRAFI®** H_2R*i* in improving pavement performance was evaluated through an extended review of available literature from wide-spread studies (over 35 publication). The contribution of H_2R*i* was examined in terms of three key actions: moisture management, moisture redistribution and filtration, and mechanical action.

The reviewed studies demonstrated the efficacy of H_2R*i* across the three key actions, affirming its positive impact on pavement performance and longevity, and moisture management.

The findings from laboratory experiments, field trials, and computational models validated the H_2R*i*'s ability in enhancing pavement structural capacity, mitigating moisture-related issues, reducing premature repair needs, and promoting overall pavement longevity. An improved resilience to moisture induced stressors is expected for pavements treated with H_2R*i*.

Independent Review of Mirafi® H_2R*i* Wicking Geotextile Performance: Findings and Lessons Learned

*This Technical Brief summarizes information related to practices, findings, and lessons learned from published studies on the use of **MIRAFI** H_2Ri woven geosynthetic for drainage and mechanical enhancement of pavement foundations. This was achieved through a critical review of existing literature.*

What is it?

H_2R*i* is a combination of woven, super high-tenacity polypropylene and wicking filaments designed to provide effective drainage and reinforcement within a pavement system.(1)

Objective and Scope

This document constitutes a critical state-of-the-art review of H_2R*i* woven geosynthetic. Topical focuses of published studies are separated into three areas: field evaluation, laboratory evaluation, and modeling effort. Table 1 presents a non-exhaustive list of literature references related to these topical focuses, providing a valuable resource of information for researchers, engineers, and professionals interested in the practical and theoretical aspects of H_2R*i*.

- ***Field evaluation.*** Several studies center around field evaluations of H_2R*i*. These field evaluations are typically part of rehabilitation projects or field test section experiments. Several researchers have investigated the practical application and performance of H_2R*i* in real-world settings, providing valuable insights into its effectiveness in various construction and infrastructure projects.
- ***Laboratory evaluation*.** Another prominent area of focus in the reviewed literature is laboratory evaluation. This involves testing the H_2R*i* in controlled environments to measure its physical and mechanical properties. Additionally, studies have aimed to quantify its wicking performance, which is crucial for assessing its role of moisture management in pavements and corresponding performance improvements. These evaluations are conducted in both standard laboratory settings and full or large-scale pavement testing facilities, allowing for a comprehensive understanding of the material's behavior.
- ***Modeling Effort.*** Some researchers have undertaken modeling studies to theoretically explain how H_2R*i* contributes to pavement structure and its impact on pavement performance. These theoretical models aim to provide insights into the underlying mechanisms of the wicking fabric and to quantify its benefits in terms of enhancing pavement performance and longevity.

Table 1 Summary of Topical Literature Related to MIRAFI H2R*i* in Reference.

Reference	Field Evaluation	Laboratory Evaluation	Modeling Effort
Schwarz, L.G. and Molino, M. (2011)[2]		♦ (F)	
Zhang, X., and Presler, W. (2012)[3]	♦	♦	
Zornberg, J.G. et al. (2013)[4]	♦		
Guo, J., et al. (2016)[5]		♦	
Weng, F., et al. (2016)[6]		♦ (F)	
Lin, C., and Zhang, X. (2016)[7]	♦	♦	
Lin, C., et al. (2016)[8]		♦	
Azevedo, M. M. D. (2016)[9]	♦	♦	
Currey, J. (2016)[10]	♦		
Yuan, H. (2017)[11]		♦	
Bradley, A.H., et al. (2017)[12]	♦		
Guo, J. (2018)[13]		♦	
Lin, C., et al. (2018)[14]		♦	♦
Guo, J., et al. (2019)[15]		♦	
Zhang, X., and Galinmoghadam, J. (2020)[16]	♦	♦	
Lin, C., et al. (2021)[18]			♦
Alvarenga, C. (2021)[19]	♦	♦	
Guo, J., et al. (2021)[20]		♦ (F)	
Biswas, N., et al. (2021a)[21]	♦		
Biswas, N., et al. (2021b)[22]	♦	♦	
Biswas, N., et al. (2021c)[23]	♦	♦	♦
Elshaer, M., and Decarlo, C. (2021)[24]	♦		♦
De Guzman, E. M. B., et al. (2021)[25]	♦		
Galinmoghadam, J., and Zhang, X. (2022a)[26]	♦		
Zaman, M. W., et al. (2022)[27]		♦	
Liu, H., et al. (2022)[28]	♦		
Zhang, W., et al. (2022)[29]			♦
Lin, C., et al. (2022)[30]		♦	♦
Galinmoghadam, J., and Zhang, X. (2022b)[31]		♦	
Lin, C., and Zhang, X. (2022)[32]			♦
Puppala, A., et al. (2023)[33]	♦	♦	♦
Biswas, N., et al. (2023)[34]	♦		
Alaska DOT&PF (n.d.)[35]	♦		

F=full-scale laboratory testing; DOT&PF=Department of Transportation & Public Facilities; n.d.=no date reported.

How Are Pavements Benefitted?

The use of H_2Ri within a pavement structure aims at benefitting the performance and longevity of pavements through three main actions.

Moisture Management Action. High moisture content in soils is well-known to compromise soil's bearing capacity, particularly after heavy rainfall or during spring thaw events. This vulnerability to high moisture conditions can, in turn, have a detrimental impact on the performance of pavements, particularly during the spring season when soil moisture levels are at their peak.

Furthermore, volumetric changes in soils, such as swelling in expansive soils or frost heaves, are often the result of excess moisture. The wicking properties of H_2Ri facilitate the accelerated drainage of pavement subgrades and granular layers. This draining action increases the stiffness and load-carrying capacity of the pavement, while also mitigating the unstable volume changes in the soil resulting from moisture variations. The unique cross-section of the filaments within the wicking yarn, coupled with suitable surface chemistry that makes the material hydrophilic (water loving), creates a suction potential through capillary action. This suction potential encourages moisture to move from the soil to the wicking filaments, increasing drainage capability.

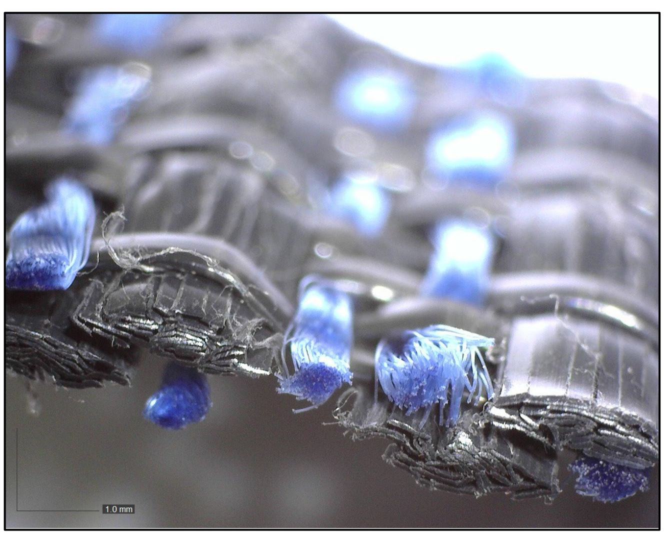
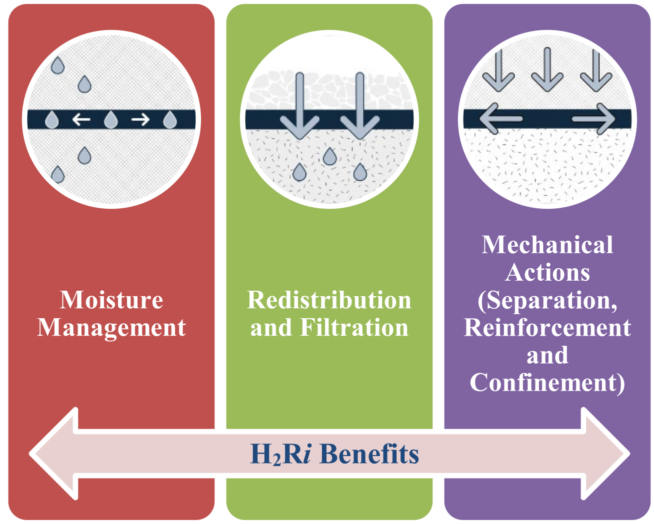


Figure 1. Close-up of H_2Ri (Black polypropylene yarn for reinforcement and stabilization and blue textured yarn for moisture management) (source: Solmax).



Moisture Redistribution and Filtration Action. The H_2Ri not only promotes the drainage of pavement subgrade soils but also serves as a medium for redistribution of excess moisture without sacrificing pavement capacity. In high plasticity soils, where moisture fluctuation can have a significant impact on soil's behavior, H_2Ri aids in redistributing moisture to minimize the risk for localized failures due to swelling and shrinkage (expansive soils are sensitive to changes in moisture content, with even a minor increase of 1 to 2% leading to severe swelling).[36] This redistribution also contributes to the pavement's overall resilience, preventing localized areas of subgrade weakness that could lead to pavement structural issues. In addition to moisture storage potential, H_2Ri plays an important role of preserving the integrity and quality of granular base material by serving as a filter media that prevents the contamination of the granular base with fines from subgrade soil. This supports potential life cycle cost savings when H_2Ri is used, as the high quality of granular base materials is preserved, and the subsequent maintenance and rehabilitation can be limited to the surface layers of the pavement.

Mechanical Action. As with other high-strength geotextiles, the H_2Ri provides mechanical stabilization to the pavement subgrades and in turn helps improve the load bearing capacity of a pavement structure. The mechanical stabilization action of H_2Ri is realized through redistribution of traffic-induced stresses on top of the subgrade, which reduces the accumulation of permanent deformation and potential for rutting in the subgrade.[21,33] Further, the H_2Ri provides lateral restraint and minimizes the potential for lateral shear flow of aggregates in the base and subbase layers. This contributes to lower rutting in these layers, further reinforcing the pavement's structural integrity and its service life.

The three actions described above for the H_2Ri have the potential to considerably enhance the durability and performance of pavements, making them more resilient to climatic events that result in excess soil moisture, such as intense precipitation storms or springtime thawing of subsurface frost. In field trials, H_2Ri treated pavement sections have fully eliminated pavement distresses as compared to control (untreated) sections (such as, severe edge cracking) and improved longevity of pavements and reduced major rehabilitation needs.

Key Findings and Lessons Learned

A summary of key findings and lessons learned related to H_2Ri's capability to enhance pavement subsurface drainage and to provide mechanical stabilization through its reinforcing action are highlighted.

Pavement Drainage Enhancement

Laboratory experiments, field investigations, and computational modelling efforts have consistently demonstrated the effectiveness of H_2Ri's wicking action in improving drainage within the pavement subgrades.

Activating a wicking zone. In controlled laboratory experiments, H_2Ri has shown the ability to establish a wicking zone extending up to 12 inches (30 cm) for clayey subgrades and between 8 to 20 inches (20–50 cm) for granular materials.[13,15] Field installation of H_2Ri at an instrumented pavement site provided a practical validation of the laboratory findings and observations related to the wicking zone.[21] For example, an application of H_2Ri on a farm-to-market road in North Texas enhanced the lateral moisture drainage capabilities of the subgrade. This improvement led to the establishment of a suction gradient between the saturated subgrade and its surrounding environment. The effectiveness of moisture drainage extended to a depth of more than 12 inches (30 cm) beneath H_2Ri into the subgrade layer.[21]

Key Findings: Pavement Drainage Enhancement by H_2Ri

- Maximum subgrade moisture reduction within 6-inch (15 cm) of H_2Ri—50% lower at 12-inch (30 cm).
- Up to 60% reduction in subgrade volumetric moisture content (VWC) observed within 6-inch (15 cm) of H_2Ri.
- Moisture reduction effective depth of more than 12 inches (30 cm).
- Increased water removal rate of H_2Ri with an increase in temperature and decrease in relative humidity (RH) between geotextile surface and air.
- Increased drainage from H_2Ri has shown to substantially reduce pavement frost heaves and pavement distresses due to swelling soils.
- Reduced moisture pooling at base/subgrade interface, unlike non-wicking geotextiles.
- Reduced soil sensitivity to precipitation events along with stable water content levels and increased strength properties during heavy rainfall.

Reducing moisture content. The reduction in moisture content within subgrade soils has also been documented through a combination of laboratory studies and field trials. For instance, at an instrumented pavement site in Texas, a significant decrease of as much as 60% in volumetric water content (VWC) was recorded within the upper 6-inch (15 cm) of the subgrade.[34] Beyond helping in the desaturation of subgrade soils, H_2Ri also improves the drainage of both granular base and subbase layers within the pavement. Laboratory testing has shown that this enhanced drainage can lead to moisture contents that are even lower than the optimum moisture content of the aggregate base materials. For example, a study by Guo et al. showed moisture content of an aggregate base with 10% fines content was reduced from 11.1% to 8% (optimum moisture content of this material was 8.6%).[15] This reduction in moisture content can influence the resilient modulus of the base material.[37] For instance, a recent study showed that achieving a moisture content 0.6% below the optimum is equivalent to a 5.5% increase in base resilient modulus.[38]

Facilitating horizontal movement of moisture. The horizontal movement of moisture from the subgrade to the exposed portion of H_2Ri occurs over the complete transverse width of the pavement embankment. Field monitoring has shown this to be the case for transverse widths of more than 72-ft (22 m).[10]

Redistributing moisture in high plasticity soils. The drainage efficacy of H$_2$R*i* is dependent on the soil type, particularly on the permeability and suction potential of the surrounding soil.[9,14] Soils with a high suction potential, such as high plasticity clays, may exhibit a reduced wicking action for the H$_2$R*i*.[31] Nevertheless, the efficiency of the wicking action also hinges on the moisture condition of the soil. In cases of saturated or oversaturated soil conditions, a more pronounced removal of moisture is observed. For low permeability and high plasticity soils, the moisture management functionality of H$_2$R*i* is predominantly realized in an effective redistribution of moisture.[23] The H$_2$R*i* helps in distributing moisture evenly in the upper part of the pavement subgrade and thus, reducing over saturated locations that may form under the wheel paths from traffic-induced stresses. In the case of soils with high organic and fines content, some literature sources indicate the need for further evaluation of soil particle intrusion (or clogging) within the wicking fiber channels.[7,10] Nonetheless, the literature examined during the preparation of this document did not yield any demonstrated evidence of this phenomenon. The microchannels in a single filament of the wicking yarns are approximately 3×10^{-4} inch (8 μm) in width and there are hundreds of filaments in a single yarn.[19] The narrow channel width and the sheer number of microchannels make it very unlikely for intrusion to occur and for any intrusion to have meaningful clogging effects. A limited testing was conducted at the Missouri University of Science and Technology to measure the wicking ability of H$_2$R*i* under soils with very high fines content.[31] Testing did not demonstrate intrusion or clogging effects in H$_2$R*i* for soils with high fines contents.

Mitigating frost-induced damage. Direct benefit of the pavement subsurface moisture management by use of H$_2$R*i* is a significant reduction in frost-induced pavement heaves and its associated pavement damage, as demonstrated in the literature.[3,10,35] Further, field instrumentation has shown that in frost susceptible regions, the excess moisture related to springtime thaw is notably reduced in pavement sections treated with H$_2$R*i*. This reduction significantly decreases the risk and potential of pavement rutting.[3,24] Field testing at Beaver Slide along the Dalton Highway in Alaska showed that the H$_2$R*i* geotextile successfully mitigated distresses caused by frost heave and thaw weakening.[3,10] The Beaver slide test site has been in service for over 12 years, demonstrating long term pavement performance improvements and moisture management abilities of H$_2$R*i*.

Reducing vertical movements and pumping. Similar to frost heaves and springtime thaw, expansive or swelling soils can result in substantial pavement damage and roughness due to vertical movements during periods of high moisture. Pavement monitoring sections, with and without H$_2$R*i*, have shown that H$_2$R*i* reduced surface rutting, lowered pavement cracking, and lessened surface movement.[9,22] Excess moisture within the subsurface layers of the pavement triggers a pumping action, causing fines from the subgrade to migrate into the granular base layers and leading to the expulsion of this material through the joints between the driving lanes and shoulder. This action accelerates pavement deterioration and fosters the development of distresses such as edge cracking.

The H$_2$R*i* has been used in field trials during a pavement rehabilitation project, where it is strategically placed at the vertical edge between the driving lanes and the pavement shoulder, as well as horizontally beneath the shoulder. Early monitoring of the pavement performance in these sections has revealed a decrease in the pumping action and a reduction in moisture content within the subgrade and granular base, especially following precipitation events.[16]

Reducing Sensitivity to precipitation events. In addition to highway applications, H$_2$R*i* has been successfully deployed to also improve capacity and performance of railway embankments. A case example from railway application in Alberta is highlighted below. The remediation using H$_2$R*i* addressed the drainage and moisture issues previously experienced at the railway embankment site prior to reconstruction.[22] In particular, the H$_2$R*i* treated section exhibited reduced sensitivity to precipitation events when compared to the other sections.

H_2R*i* Field Trial Case Example: Improving Railway Embankment[22]

- A 45-meter section of a railway embankment in Fort Saskatchewan, Alberta, underwent reconstruction as part of a Canadian Pacific Railway's Grade Stabilization/Remediation Plan.
- The reconstruction involved replacing ballast and sub-ballast with clean materials and installing two geotextiles: **MIRAFI** RS580i reinforcing geotextile and **MIRAFI** H_2R*i* wicking geotextile to address drainage and moisture issues.
- The study allowed for direct comparison between the remediated and control sections, with both sections equipped with sensors to measure volumetric water content (VWC), among other parameters.
- Key findings from the first year of monitoring are:[22]
  - The remediated section showed reduced sensitivity to precipitation events compared to the control section.
  - VWC levels in the remediated subgrade remained stable even during heavy rainfall.
  - The remediated section exhibited consistent and higher minimum strength levels than the control section, suggesting improved embankment bearing capacity during heavy rainfall.

Reinforcement Benefits

The reinforcing action of geosynthetics and its associated benefits to the pavement structural capacity and overall performance have been well documented.[38] Existing literature demonstrated as much as six fold increase in the traffic benefit ratio (TBR) with the use of geosynthetic (TBR is defined as the ratio of allowable traffic to structural failure of pavement with and without use of geosynthetics).[39]

Reinforcing mechanisms. The benefits of the reinforcing action of H_2R*i* is realized through three mechanisms, namely lateral restraint, increased bearing capacity, and membrane support.[38] Lateral restraint is achieved through the frictional interaction between the geosynthetic layer and the pavement layers above and below it. This reduces the potential of lateral shear flow occurring in the geomaterial directly adjacent to the H_2R*i*.

The increased bearing capacity of the pavement structure is a result of the H_2R*i*'s reinforcing action, which disrupts the formation of the shear flow originating from the wheel load's edge and continuing through the base and subgrade layers.

Lastly, the membrane support mechanism of H_2R*i* acts by generating tension within the H_2R*i* layer to limit the vertical deformation of subgrade material beneath it. This results in a redistribution of stresses; causing vertical stresses to be transmitted over a larger subgrade area with reduced magnitude. Together, these three mechanisms of H_2R*i* effectively address rutting in subgrade and unbound layers, which is one of the primary pavement structural distresses.

Increasing pavement structural capacity. The structural benefits of H_2R*i* in improving capacity and performance of pavements have been studied through laboratory testing, field testing, and computational modelling. In the laboratory testing conducted on silty soil, the use of H_2R*i* has resulted in an increase of number of load repetitions by factors of 3.4 to 8.9 to achieve the same amount of rut depths (permanent deformation) under repeated loadings.[2] Laboratory tests conducted on granular base materials have shown a reduction in the permanent deformation of 9% and 16% for dry and saturated conditions, respectively.[2]

The reinforcing benefits of H_2R*i* have also been observed in monitored field pavement sections that compared control sections with those treated with H_2R*i*. For example, pavement sections treated with H_2R*i* on the Dalton Highway in Alaska have eliminated dips or settlement in areas with subgrade "soft spots".[10] Similarly, a low volume roadway site in northern New England showed 25% to 45% increase in the subgrade resilient modulus (backcalculated using falling weight deflectometer measurements) when treated with H_2R*i*.[24]

Reduced pavement thickness. Multilayered elastic analysis for a pavement structure with H_2R*i* has shown 8 to 11% improvements in the rutting potential through reinforcing action.[29] A coupled hydraulic-mechanical finite element (FE) analysis of pavement structures with and without H_2R*i* has shown that pavements incorporating H_2R*i* can achieve equivalent pavement structural performance while using base courses with thicknesses reduced by as much as 49%.[32]

The cost advantages of using H_2R*i* have also been demonstrated in field studies. Pavement monitoring sections in Texas have been designed and constructed where H_2R*i* treated sections used 2-inch (5 cm) thick asphalt concrete (AC) layers as opposed to 4-inch (10 cm) AC layers for the untreated sections.[33] The H_2Ri treated sections with thinner AC layers exhibited lower subgrade vertical stresses based on in-situ measurements when compared to the control sections without H_2Ri and thicker AC layers. Furthermore early-age pavement monitoring of these sections revealed lower surface rutting for H_2Ri treated sections as compared with control sections.[33]

Key Findings: Reinforcing Benefits of H_2Ri

- Reinforcing effects can result in reduced pavement structure (response testing indicated as much as 40–50% lower base thickness requirements).
- Lab testing showed 3.4–8.9 times increase in number of load repetitions to achieve same rut depths as control case.
- Early pavement performance results for moisture susceptible (expansive) soils show reduced surface rutting and less surface movement.

Characterization and Simulation of H_2Ri

A study by Lin et al. involved comprehensive laboratory tests to assess the properties of H_2Ri and its interaction with surrounding soil.[14] It determined the working mechanism and functional range of the H_2Ri and quantified the soil-geotextile system's drainage ability through numerical simulations. The researchers demonstrated that H_2Ri effectively drains capillary water in the in-plane direction, thus, reducing the base course's water content by 2.2% from the optimum level and increasing the corresponding resilient modulus by 2 to 3 times. The following summarizes two key findings from the laboratory test results and corresponding numerical modeling.[14]

- ***Laboratory test results.*** The soil-geotextile system's working mechanism and its effective range is theoretically explained based on laboratory test results. Researchers concluded that H_2Ri functions both as a capillary barrier and as an efficient drainage material in the in-plane direction for removing water from pavement structures. The deep grooves within the wicking fibers have high specific surface areas, enabling them to effectively retain and transport water, especially in unsaturated conditions. This unique characteristic allows the H_2Ri to maintain its effectiveness until the suction level reaches the inner-yarn air-entry value of 37 psi (254 kPa).
- ***Numerical modeling results.*** The performance of pavement structures with and without H_2Ri is assessed using numerical modeling and the measured characteristics for soil and H_2Ri. The results confirmed the effectiveness of the wicking fabric in water removal, with a 2.2% lower average water content above the fabric and increased resilient modulus. The wicking effect extended to a depth of 16-inch (0.4 m) beneath the fabric.

Characteristics of H_2Ri: Summary of Measured Properties.[14]

- **Initial Tangent Modulus:**
  - H_2Ri exhibits a linear stress-strain curve.
  - Initial tangent modulus values determined using wide-width tensile strength tests are 493 MPa (cross-machine direction) and 218 MPa (machine direction).
- **Geotextile Water Characteristic Curve (GWCC):**
  - GWCC represents the fabric's ability to retain water under unsaturated conditions.
  - H2Ri is expected to have a directional GWCC, with higher water-holding capacity in the wicking direction and lower capacity in the cross-plane direction.
  - GWCC is influenced by its pore size distribution and apparent opening size (AOS).
- **Testing Methods:**
  - Tests are designed to assess the fabric's water retention properties under different conditions and suction levels.
  - Capillary rise, pressure plate, and salt concentration tests are performed to determine the drying GWCC in the in-plane (wicking) direction.
  - Constant head test is used to determine the saturated hydraulic conductivity.
- **Saturated Hydraulic Conductivity:**
  - H_2Ri hydraulic conductivities are directional, with the in-plane conductivity expected to be higher than the cross-plane conductivity.
  - The saturated in-plane hydraulic conductivity (i.e., transmissivity) of H_2Ri is determined to be 6.20×10^{-4} m/s.
- **Soil-Geotextile Interface Frictional Angle:**
  - Interface frictional angle between H_2Ri and aggregate base is determined using a large-scale direct shear test. The frictional angle helps understand the interaction between the geotextile and base.
  - Interface frictional angle sensitivity to water content variations in soil is minimal (a peak value of 47.5° at 2% water content and reduced to 39.4° as the water reached 10.5%). Thus, demonstrating the effectiveness of the H_2Ri in continuing to provide lateral restraint at high water contents.

Lin and Zhang introduced a coupled hydraulic-mechanical FE model that accounts for localized climatic conditions.[(32)] The model was calibrated and applied in three case studies to assess the dynamic resilient behavior of a base course under varying climatic conditions. Two types of geotextiles were used in the numerical simulation, each with specific mechanical and hydraulic properties. The geotextile water characteristic curves (GWCCs) for the H_2R*i* and non-wicking geotextile were measured in the laboratory. The mechanical interactions between the geotextile and soil were also established through large-scale direct shear tests. Using laboratory measured properties in the numerical simulations, researchers observed that non-wicking geotextiles can cause excess water accumulation at the soil-geotextile interface due to the capillary break effect, leading to a significant reduction in reinforcing benefits. In contrast, H_2R*i* efficiently drains excess water out of pavement structures, increasing the effective resilient modulus by 51%.[(32)]

Installation Considerations

The proper installation of H_2R*i* plays an important role in realizing its intended purpose. Practical considerations and recommended practices associated with the installation process are identified in the literature.

Guidelines and information consistent with generally accepted practices of identifying, handling, storing and installing geosynthetic materials for most roadway applications can be found in "Installation Guidelines for MIRAFI® H_2R*i* Moisture Management System."[(17)] Some key aspects addressed in the document include:

- **Proper handling and storage**. The document details how to identify, store, and handle the material, including protection against moisture absorption, ultraviolet radiation, and elevated temperatures in excess of 140°F (60°C). This is essential in order to preserve the physical properties of the H_2R*i*.
- **Placement location(s).** The appropriate placement of H_2R*i* within the pavement cross section is determined based on the project's unique conditions. The common location is at the subgrade/base interface in pavement structures. Typically, H_2R*i* is positioned at least 12 inches (30 cm) above the adjacent groundwater table or free water surface outside the installation. However, in flood-prone areas, it can be placed below the waterline to expedite drying after flood events. The document includes examples of application installations for enhanced lateral drainage/pavement reinforcement, frost heave, and surficial intrusion.
- **Geosynthetic installation.** Instructions for the proper installation of H_2R*i* is provided, including subgrade preparation, equipment requirements for very soft or sensitive subgrade soils, directional overlap as a function of subgrade strength, and placement orientation.
- **Termination techniques.** Different termination methods are discussed for optimizing water removal, such as traditional (no outlet), edge termination, daylighting, bio-wicking, and piping. The H_2R*i*'s termination details are critical to the performance of the system.
- **Fill placement.** Guidance on the proper placement of aggregate fill over the geosynthetic layer is offered, including precautions for trafficking vehicles and operating construction equipment.
- **Aggregate fill considerations.** Recommendations are provided on the preferred aggregate fill gradation for roadway applications including unpaved roads.
- **Installation and repairs.** Repair methods for utility cuts or damaged areas, including the placement of repair panels, are addressed.

The following summarizes observations identified in the literature associated with the performance of H_2R*i* under specific project conditions in relation to its installation process.

Fabric overlap.[(3,10,18)] The literature underscores the critical role of the careful overlap of H_2R*i* geotextile during installation. Proper fabric-to-fabric contact and careful overlap are pivotal for achieving the desired performance and longevity of the H_2R*i* system (e.g., impeding water from flowing back to the base course). These factors can significantly impact the system's effectiveness in managing water and moisture.

Prolonged inundation and subgrade moisture.[7,19] Research reveals that subjecting the exposed portion of H_2Ri to extended inundation can elevate the subgrade moisture content. This observation is crucial for understanding the system's response to varying moisture conditions and highlights the potential for managing subgrade moisture levels through controlled exposure and drainage adjustments.

Optimal drainage via exposed ends.[7,10,13,16,26] A noteworthy finding in the literature is that exposing the ends of wicking geotextile components enhances their drainage performance. Optimal performance was observed when the ends of the wicking geotextile remained exposed to the atmosphere. This practice aims at maximizing drainage efficiency of the H_2Ri system, particularly in applications where water management is needed.

Increased efficacy with bio-wicking system.[7] In this approach, local vegetation is used to draw water from the system through their roots, away from the exposed edge of the H_2Ri. Selective roadside vegetation planting promotes the evapotranspiration process, as demonstrated in elemental and full-scale field tests, where the bio-wicking system improved the efficiency in managing capillary water within the base course.[7] The vegetation functioned as a "pump," vaporizing water from the soil, with H_2Ri acting as a conduit to sustain saturation under negative pore water pressures. This prevented the H_2Ri from becoming overly dry. Furthermore, the bio-wicking system displayed the ability to keep draining capillary water with water volume decreasing even after testing has been concluded.

These observations from the literature support the importance of proper installation, offering insights into the significance of seam quality, the understanding of the effects of inundation on subgrade moisture control, and the strategic exposure of H_2Ri geotextile ends. Incorporating these findings into the installation practices contributes to the overall performance and functionality of H_2Ri systems. There are instances where installation of culverts is impractical or uneconomical where H_2Ri can provide moisture redistribution efforts; this has been successfully deployed for expansive soils in Texas.[42]

Quick Installation Tips

- Minimum exposed length of 16-inch (0.4 m).
- Exposed portions should be kept out of standing water.
- Install culverts prior to fabric placement.
- Minimize soil evaporation and enhance drainage through vegetation transpiration to continuously extracts water and vapor from the soil.

Overall Summary

The literature review for over 35 publications related to H_2Ri represents a critical step in consolidating and summarizing the existing knowledge on the pavement performance improvements and moisture management abilities of H_2Ri. The widespread extent of published scientific literature on this system clearly demonstrates that comprehensive laboratory, field and computational investigations have been conducted on H_2Ri. The overall contributions of H_2Ri to pavement structural capacity and performance have been shown due to its ability for lowering or redistributing moisture in subgrade (and granular layers). The mechanical contributions through reinforcing action and shear failure prevention have also been studied through laboratory testing, computational modelling, and field trials. Field trials have consistently demonstrated improved pavement performance for H_2Ri treated sections compared to control (untreated) sections. This is supported by over 12 years of in-service performance data.

Beneficial contributions of the H_2Ri to the pavement performance can be narrowed to two primary gains: one that is a continuous fixed improvement, and second that is an improvement during times of high vulnerability.

The first continuous fixed improvement comes from the mechanical reinforcement and stabilization action that lowers subgrade rutting potential at all times of pavement service.

The second advantage of H_2Ri is when pavements are most vulnerable to rutting and damage, i.e., during time of excess subsurface moisture. The wicking and moisture storage ability of H_2Ri ensures that pavement subgrade and granular base is desaturated during most of its service life. Not only does this substantially improve pavement life, but this also significantly lowers secondary distresses from excess moisture, such as, frost heave and swelling soils.

In addition to the above primary gains, H_2R*i* also provides a "value added" proposition through its filtration action and its ability to lower thicknesses of other pavement layers due to accelerated recovery of pavements in the post-storm periods. By preventing migration of fines into base courses, it adds to the preservation of base courses that will provide life cycle cost advantages. In post flooding conditions, pavements treated with H_2R*i* will undergo speedy recovery from inundation and subgrade saturation, this in turn will make them better suited to serve as emergency access routes.

Dual Benefits of H_2R*i*

- Provide continuous support for subgrade stability.
- Provide substantial resilience during periods of heightened vulnerability.
- Ultimately contributing to the long-term performance and longevity of pavements.

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Key words—Pavement, geosynthetic, wicking, moisture redistribution, reinforcement.

Notice—Drs Eshan Dave and Elie Hajj acted as their own agents, and they are not agents of their own universities, and their universities are in no way involved in this activity or responsible for its conduct or product.

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