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TECHNOLOGICAL ASPECTS OF PAVEMENT IMPROVEMENT OF BRIDGES AND HIGH AQUAPLANING AREAS

The sharp increase in traffic intensity, the constant increase in weight loads on road surfaces, the use of outdated technologies and low-quality construction materials lead to an accelerated deterioration in the operational characteristics of motorways. This results in typical defects such as rutting, potholes, cracks, deformations and aquaplaning, which directly affect road safety. These processes are particularly critical on artificial structures such as bridges and overpasses, where water drainage is limited and geometric conditions are complex. Weather conditions, in particular heavy summer rains and seasonal snowmelt, are an important factor in the increased risk of accidents in areas with inadequate drainage. Areas with an increased likelihood of aquaplaning require special attention, where traditional design and construction methods are ineffective or technically impossible to implement. In such conditions, promising solutions include the use of the latest road construction materials and structures, in particular porous asphalt concrete and geosynthetic materials with drainage properties. They effectively reduce the depth of the water film, increase the coefficient of wheel adhesion to the road and extend the service life of the pavement. The study found that in order to effectively reduce the risk of aquaplaning, it is necessary not only to comprehensively change the geometric parameters of the road surface (increasing slopes, organising longitudinal and transverse drainage systems, installing wells and gutters), but also to introduce innovative types of road surfaces with improved drainage properties. In areas where geometric reconstruction of the road is limited or technically impossible, for example, within urban areas, on bridges or in tunnels, the use of materials with high water permeability and the ability to quickly remove moisture from the surface becomes particularly relevant. During the study, an analysis was carried out of the relationship between pavement roughness, water layer depth and the coefficient of friction. Experimental measurements of wheel adhesion to the surface were performed under various weather conditions, speeds and loads. Traffic scenarios were also *modelled for different longitudinal slope angles, pavement types and braking modes. In addition, the results showed that although the initial investment in the use of the latest materials is slightly higher compared to traditional technologies, the total costs of maintenance, repair and elimination of the consequences of road accidents are significantly reduced. The payback of innovative solutions is already observed in the medium term, which confirms the feasibility of their implementation.*

Key words. Aquaplaning, pavement, drainage materials, porous asphalt concrete, geosynthetics, traction coefficient, road safety.

Introduction. The increasing complexity and intensity of modern transportation systems place significant demands on the performance, safety, and durability of road infrastructure. Among the most vulnerable elements of road networks are bridges and roadway sections prone to aquaplaning – phenomena that not only reduce the operational efficiency of transportation routes but also pose critical safety risks to motorists. The combination of structural limitations, climatic influences, and increased axle loads creates conditions under which traditional pavement designs often prove insufficient. Consequently, the technological improvement of pavement structures in such critical zones has emerged as a priority task in contemporary road engineering.

Bridges and overpasses are particularly susceptible to rapid wear and degradation due to their exposure to environmental factors from all sides, as well as the inability to transfer moisture into the underlying soil layers. Unlike standard road sections, bridges lack the natural subgrade filtration capacity and are often constructed from rigid base structures such as reinforced concrete or steel, which respond differently to temperature variations and dynamic loads. In winter, the surface temperature of bridge decks tends to be lower than that of adjacent road sections, increasing the likelihood of icing. In warmer seasons, the impermeability of the structure contributes to water accumulation during rainfall, increasing the risk of aquaplaning. Therefore, pavement solutions for bridges must consider both thermal dynamics and drainage capabilities more carefully than standard roadways.

Another critical issue is aquaplaning – the loss of tire traction caused by a layer of water between the road surface and vehicle tires. This effect is especially hazardous at high speeds and is a known contributor to accidents on highways and elevated sections of the road where water drainage is insufficient. Aquaplaning typically occurs due to low pavement macrotexture, ineffective cross-slope drainage, and poor-quality surface materials. Traditional dense-graded asphalt mixtures often lack the permeability required to quickly evacuate water from the contact area between the wheel and pavement, making such sections of the road highly risky during and after precipitation events.

Technological advancement in pavement design for these high-risk zones necessitates the application of innovative materials and design methods that go beyond conventional asphalt concrete. Porous asphalt mixtures, for instance, provide a high degree of permeability, allowing water to pass through the pavement surface into underlying drainage layers, thereby significantly reducing surface water buildup. Similarly, the integration of geosynthetics – such as drainage geocomposites and geotextiles – has been shown to enhance the water management capacity of the pavement system while contributing to its structural stability.

In addition to materials, surface geometry and texture also play a critical role. The macro- and micro-texture of a pavement influence the frictional interaction between the road and tires, especially under wet conditions. Surface treatments such as thin overlays with high-friction aggregates, grooving, and surface grinding have proven effective in improving water dispersion and maintaining traction. However, such solutions must be carefully selected and adapted to the specific structural and environmental conditions of the location – especially when applied on bridges or in areas with known aquaplaning risks.

Moreover, the technological improvement of such pavements must align with sustainability and lifecycle performance goals. High-performance asphalt mixtures with polymer-modified binders, fiber reinforcements, or recycled materials not only enhance resistance to deformation and moisture damage but also contribute to longer service life and reduced maintenance needs. From an economic perspective, while these technologies may involve higher initial costs, they are often justified by significant reductions in accident rates, extended repair intervals, and lower total ownership costs.

This paper explores the critical technological aspects associated with improving pavements in bridge zones and areas with high aquaplaning potential. It reviews current challenges, examines advanced materials and drainage techniques, and presents design recommendations aimed at enhancing safety, durability, and hydrological performance. Through a combination of structural innovation, material science, and performance evaluation, it is possible to significantly mitigate risks associated with poor surface drainage and elevate the standards of modern roadway infrastructure.

Problem statement. The issue of pavement deterioration and traffic safety in areas with a high risk of aquaplaning, particularly on bridges and elevated road sections, presents a significant engineering and societal challenge. These locations are characterized by poor drainage, exposure to dynamic traffic loads, and geometric limitations that contribute to the rapid degradation of pavement surfaces and a high incidence of traffic accidents, especially during adverse weather conditions. Traditional materials and road construction techniques are often ineffective under these circumstances, which leads to reduced service life, higher maintenance costs, and increased risks for road users. Ensuring the long-term functional performance, durability, and safety of such critical road infrastructure requires technological innovations that address both structural and hydrological vulnerabilities.

Literature review. A number of studies have proposed partial solutions to the problem by introducing porous asphalt mixtures for enhanced drainage, using geosynthetic materials to support substructure stability, and modifying surface textures to improve friction in wet conditions. Research shows that porous asphalt significantly reduces surface water accumulation, while geosynthetics improve moisture control and increase the mechanical reliability of pavements. Additionally, investigations into surface micro- and macrotexture have shown promising results in improving tire-road interaction. However, most existing works are limited to general roadway applications and do not fully address the unique challenges associated with bridge structures or road segments with strict geometric and spatial constraints. There is also insufficient integration of these approaches into a unified pavement design concept, and a lack of comprehensive technical and economic evaluations that would support their widespread adoption. The works on the study of the influence of various factors on the asphalt concrete pavement of roads and bridges, existing design solutions, technologies and materials for increasing the durability of the pavement are reviewed and analyzed. The following scientists made a significant contribution to solving the problems: A.M. Boguslavsky, G.O. Bonchenko, V.I. Bratchun, E.V. Kotlyarsky, B.S. Radovsky, K.L. Fuchs.

Purpose of the article. This article aims to develop and justify an integrated technological approach for improving pavement structures on bridges and in areas prone to aquaplaning. The study focuses on evaluating the effectiveness of porous asphalt concrete and drainage-capable geosynthetic materials, analyzing the influence of surface roughness on tire grip under wet conditions (ideal tyre grip is achieved on dry asphalt pavement (Fig. 1), and conducting a technical and economic assessment of proposed design solutions. The goal is to offer practical, cost-effective recommendations that improve road safety, extend pavement life, and ensure consistent performance under variable environmental and operational stresses. However, when there is excessive moisture on the roadway and high speeds, effective drainage becomes impossible.


Figure 1. Tyre grip on dry road surfaces

Summary of the main research material.

Today, the problem of tyre wear is the exception rather than the rule, but at the same time, road accident statistics show a significant number of accidents related to this phenomenon, and the danger associated with hydroplaning threatens not only the car in this situation, but also all road users. Incorrect actions by the driver when recovering from aquaplaning can result in the vehicle leaving the road and being driven onto the oncoming lane, which can increase the number of road traffic accidents and the likelihood of fatalities. At the same time, tyres reach their limit when the tread depth is exceeded (Fig. 2) and the tyre loses contact with the road surface.

Increasing traffic intensity, changing climatic conditions and the widespread use of outdated technologies in road construction lead to deterioration of the technical condition of the road surface. Particularly dangerous are areas with a high risk of aquaplaning, which occurs when moisture accumulates on the surface and a water film forms between the tyre and the road. This leads to a sharp decrease in traction and, as a consequence, an increase in the probability of road accidents. In this paper, design solutions aimed at improving the traction properties of the pavement under wetting conditions through the use of drainage layers and materials are proposed and investigated.

Figure 2. Stages of aquaplaning

Aim and objectives of the study The aim of the work is to develop and techno-operational evaluation of pavement designs that reduce the risk of aquaplaning. To achieve this goal, the following objectives were set:

- to investigate the causes and conditions of aquaplaning;
- to analyse the influence of traction coefficient on traffic safety;
- to review existing solutions with draining coatings;
- to develop a design using porous asphalt concrete and geosynthetic materials;
- calculate the traction properties and evaluate the effectiveness of the proposed solution.

The most effective way to reduce aquaplaning is to increase the degree of roughness. One of the key characteristics of the road surface, which determines the safety of driving in wet conditions, is its ability to provide a reliable grip of the car tyres with the surface of the carriageway. This is particularly important during periods of rain or snowmelt, when the risk of aquaplaning increases. Traction qualities of the pavement are quantitatively assessed using the coefficient of adhesion, determined with the help of traction and coupling device type PKRS on a wet surface in accordance with the requirements of DSTU B B.2.3-2-2000 and DSTU B B.2.3-8-2003. In accordance with the standard DSTU 3587-97, the minimum permissible value of the coefficient of adhesion should be not less than 0.3, which provides safe driving conditions at the established regulatory speed. Increasing the surface roughness contributes to the improvement of traction characteristics due to more effective water drainage and prevent the formation of a water wedge under the wheels. However, excessive roughness can cause an increase in traffic noise and vibrations, which reduces passenger comfort and accelerates wear and tear of vehicle components. Thus, it is important to achieve an optimum balance between traffic safety and user comfort when designing and operating road surfaces [15-17].

Table 1. Dependence of traction coefficient on road surface condition

Pavement type	Pavement condition	Coefficient of adhesion
Asphalt concrete	Dry	0,6–0,8
Asphalt concrete	Wet	0,3–0,5
Asphalt concrete (smooth) Wet	Wet	0,2–0,3
Crushed or rough gravel Wet	Wet	0,4–0,6

From this table 1, a graph (Fig. 3) was produced to give a better example of the effect of roughness on traction coefficient (dry and wet).

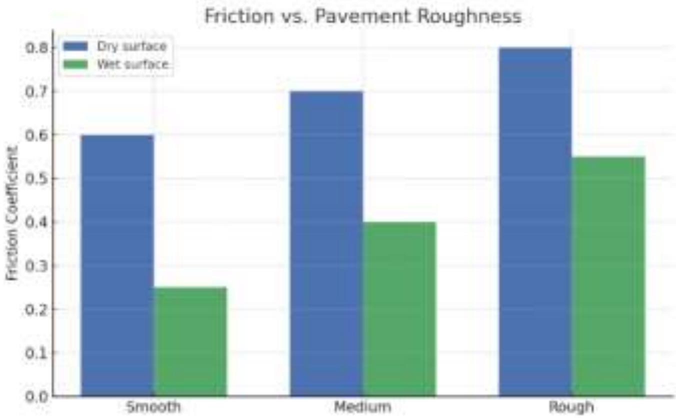


Figure 3. Graph of dependence of traction coefficient on road roughness

O.M. Reznik and A.O. Belyatinsky have very well considered in their research the influence of roughness on aquaplaning. [1-4] have staked on the improvement of construction materials used in road paving and the improvement of the paving technology itself. Today, asphalt concrete is the most common material used for the construction of improved pavements on motorways of the highest technical categories. In Europe such pavements make up more than 90 % of the total length of roads on which more than 40 % of cargoes are transported. In Ukraine roads of I-II technical categories also in 95% of cases have asphalt concrete pavement, which is due to a number of undeniable advantages of this material - high maintainability, manufacturability, quietness and absence of dust formation. The top layers of the road structure are usually made of hot dense fine-grained asphalt concrete of types ‘A’ and ‘B’, the properties of which are regulated by DSTU B B.2.7-119:2011. Hot asphalt concrete mix contains a binder - bitumen of BND 90/130, BND 60/90 or BND 40/60 grades, and is paved at a temperature of 140-160 °C. The final formation of the structure takes place after compaction with rollers. Asphalt concrete is characterised by high durability, water resistance, water resistance, as well as the ability to elastic and plastic deformations, which provides the pavement with elasticity, roughness and reliable adhesion to car tyres. Researches of scientists (O.M. Reznik, A.O. Belyatinsky, K.V. Krayushkina, etc.) proved that when bitumen interacts with mineral components (crushed stone and sand), complex physical and chemical intermolecular processes occur, which influence not only the structure of the mixture at the moment of laying, but also the behaviour of the pavement during operation [1-6].

Dense asphalt concrete is able to resist atmospheric influences, preventing water penetration into the underlying layers of the pavement. However, on road sections with complex geometries, increased rainfall and specific terrain, the water resistance of asphalt concrete can, on the contrary, favour the accumulation of water on the surface. This increases the risk of aquaplaning, reduces traffic safety, causes accidents and may even interrupt traffic flow. This makes the use of porous asphalt pavements for drainage purposes in hazardous areas relevant. This material has a residual porosity of more than 10 % and is a mixture of mineral components with a reduced bitumen content. It is used in the top layers of pavements to accelerate water drainage from the surface, prevent water stagnation and reduce the risk of aquaplaning. Table 2 was created to illustrate the advantages of this type of material.

Table 2. Comparative characteristics of dense and porous asphalt concrete

Parameter	Dense Asphalt Concrete	Porous (Drainage) Asphalt Concrete
Residual Porosity	3–5%	>10%
Bitumen Content	Standard	Reduced
Water Permeability	Low (water does not penetrate deeply)	High (water drains through the structure)
Purpose	Universal, including urban use	For areas with aquaplaning risk
Surface Roughness	Medium to high	High
Shear and Wear Resistance	High	Lower, requires proper design
Compressive Strength	High	Lower than dense equivalent
Water Drainage Efficiency	Low, water accumulation possible	Very high, eliminates water film
Traffic Noise Level	Medium	Lower due to porous structure sound absorption
Application	Majority of road network	Areas with high precipitation and aquaplaning risk

Based on Table 2, a more visual graph was created (Fig. 4).

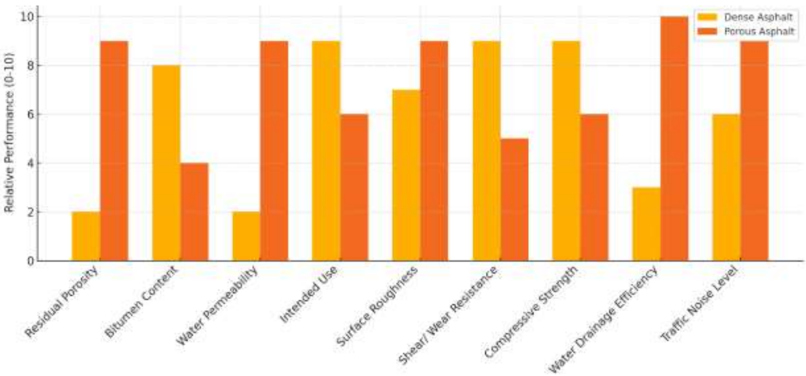


Figure 4. Comparison of Dense and porous asphaltconcrete

Advantages of porous asphalt concrete:

This type of asphalt concrete has a number of advantages:

- High traction properties due to the increased content of crushed stone fractions.

- Water permeability, which reduces water accumulation on the surface and reduces splashing during rain. This in turn reduces the risk of aquaplaning and improves driving safety.

- The rough surface of porous asphalt helps to reduce the noise generated when tyres make contact with the pavement.

Disadvantages of porous asphalt:

However, this material also has disadvantages:

1. Reduced durability due to high porosity.

2. Accelerated aging of bituminous binder, as oxygen penetrates more actively into the structure of the mixture.

3. Rapid freezing of the lower layers of the pavement.

4. Absence of heat-insulating properties typical for dense asphalt concrete mixtures.

5. Limitations during winter maintenance: it is not recommended to use sand-salt mixtures and technical salt in pure form, as it leads to clogging of pores and penetration of chlorides into the underlying layers of the road structure.

Today in Ukraine there are materials available to improve the properties of porous asphalt concrete:

1. Modifying additives (adhesion, polymeric) that increase the durability of bitumen.

2. Modern anti-icing agents preventing the formation of ice and slipperiness.

3. Geosynthetic materials (GM), used since the 90s in various layers of road structures. They fulfil the functions of reinforcement, drainage, separation and strengthening.

For effective water drainage in areas of high risk of aquaplaning, it is proposed to lay basalt continuous fabric of PSB-D grade (impregnated with polymer) under the top layer of the pavement. This method was also recommended by scientists Belyatinsky and Reznik.

Advantages of this solution:

- Prevents moisture accumulation in the road structure.

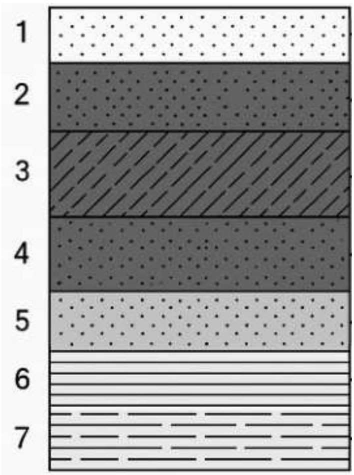
- Increases the strength and durability of the pavement.

- Evenly distributes the load from traffic, improving the stress-strain state of the entire structure.

This technology, developed by the author, has been successfully tested and proved its effectiveness in draining surface water and preventing aquaplaning.

Porous asphalt concrete (PAB) specimens made using a 15% open pore formulation were tested for water permeability and freeze-thaw resistance. The average filtration coefficient was 1.5×10^{-3} m/s, an order of magnitude higher than that of dense asphalt concrete mixtures. After 25 freeze-thaw cycles, the compressive strength decreased by less than 10%, indicating good frost resistance of the material.

Numerical calculations were performed using a Horne's Equation model that takes into account vehicle speed, water film depth and pavement characteristics. For a conventional pavement without drainage, the critical aquaplaning speed was 78 km/h at a water thickness of 3 mm. For the pavement with PAB and a cross slope of 3%, the aquaplaning speed increased to 108 km/h. This means that drainage solutions significantly extend the range of safe driving speeds in rain [1-4]. Based on these requirements, the following road surface structure was developed (Figure 5).



Porous asphalt concrete on crushed stone aggregate	5.0
Crushed stone-mastic asphalt concrete (PSV-D, fine-grained)	0,1
Coarse-grained asphalt concrete	10
Cement-treated crushed stone mixture	15
Crushed stone-sand mixture C-5, according to DSTU B V.2.7-30:2013	20
Coarse sand, according to DSTU B V.2.7-32:95	20
Subgrade soil — heavy silty clay	-

Figure 5. Structure of the developed road surface

The experimental road section was paved with a 5 cm thick PAB layer underlain by a crushed stone-sand drainage layer. Drainage, rutting and traction properties of the pavement were monitored for 12 months. According to the results, the time to completely remove water from the surface in heavy rain (10 litres/m² in 20 minutes) was less than 3 minutes, while for the control section with conventional asphalt concrete it was more than 10 minutes. The slip resistance (BPN) was maintained at >60, which corresponds to a high level of safety.

A comparative analysis of the cost of pavement construction showed that the introduction of drainage pavement and geosynthetic materials increases capital costs by 12-15 %. However, due to the reduction of repair costs, reduction in the number of accidents and increase in the service life of the road, the overall cost-effectiveness of such solutions can be seen after 5-7 years of operation.

The conducted research has confirmed high efficiency of application of drainage pavements, in particular porous asphalt concrete (PAB), and design solutions aimed at reducing the risk of aquaplaning.

The results obtained allow us to formulate the following main conclusions:

1. The mechanism of aquaplaning reduction is provided by increased water permeability of pavements and accelerated water removal from the contact zone of the tyre with the road. PAB with the content of open pores 15-20 % provides filtration coefficient 5-10 times higher than traditional asphalt concrete.
2. Mathematical modelling has shown that drainage structures can increase the critical aquaplaning velocity by 30-40%, which significantly improves traffic safety in heavy rainfall conditions.
3. Polygon tests have confirmed that in heavy rainfall, water on the PAB surface is removed 3 times faster than on a conventional pavement. The coefficient of adhesion remains at a high level throughout the entire service life, which is important for accident prevention.
4. The use of reinforcing geosynthetic layers additionally increases the resistance of the road structure to deformations and rutting, especially in conditions of frequent water saturation of the base.
5. Economic evaluation has shown that the additional costs of the drainage layer and reinforcing materials are recouped within 5-7 years by reducing operating costs and improving traffic safety.

Recommendations:

- When designing highways of I and II categories in regions with increased intensity of precipitation, it is advisable to provide for the use of draining asphalt-concrete mixtures and cross slopes of at least 3 %.
- The use of geosynthetic interlayers between pavements is recommended to increase service life, especially in the case of weak or water saturated subgrades.
- Incorporating modelling techniques (e.g. Horne model calculations) into regulatory design approaches can improve the accuracy of aquaplaning risk assessment and the effectiveness of the solutions applied.
- More research on the durability of ASPs under real traffic and climatic conditions is needed to further optimise the mixes.

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Армен АТИНЯН, Махмуджан ДЖАЛАЛОВ, Світлана БРАТІШКО, Роман ТКАЧЕНКО, Олександр САВЧЕНКО

Технологічні аспекти поліпшення дорожнього покриття мостів і ділянок з високим аквапленуванням

Різке збільшення інтенсивності руху, постійне збільшення навантаження на дорожнє покриття, використання застарілих технологій та низькоякісних будівельних матеріалів призводять до прискореного погіршення експлуатаційних характеристик автомагістралей. Це призводить до типових дефектів, таких як колії, вибоїни, тріщини, деформації та аквапланування, які безпосередньо впливають на безпеку дорожнього руху. Ці процеси є особливо критичними на штучних спорудах, таких як мости та естакади, де водовідведення обмежене, а геометричні умови є складними. Погодні умови, зокрема сильні літні дощі та сезонне танення снігу, є важливим фактором підвищення ризику аварій в районах з недостатнім водовідведенням. Особливої уваги потребують ділянки з підвищеною ймовірністю аквапланування, де традиційні методи проектування та будівництва є неефективними або технічно неможливими для реалізації. У таких умовах перспективними рішеннями є використання новітніх дорожньо-будівельних матеріалів і конструкцій, зокрема пористого асфальтобетону та геосинтетичних матеріалів з дренажними властивостями. Вони ефективно зменшують глибину водяної плівки, збільшують коефіцієнт зчеплення коліс з дорогою та подовжують термін експлуатації дорожнього покриття. Дослідження показало, що для ефективного зниження ризику аквапланування необхідно не тільки комплексно змінити геометричні параметри дорожнього покриття (збільшити ухили, організувати поздовжні та поперечні дренажні системи, встановити колодязі та водостоки), але й впровадити інноваційні типи дорожнього покриття з поліпшеними дренажними властивостями. У районах, де геометрична реконструкція дороги обмежена або технічно неможлива, наприклад, у межах міських територій, на мостах або в тунелях, особливо актуальним стає використання матеріалів з високою водопроникністю та здатністю швидко видаляти вологу з поверхні. Під час дослідження було проведено аналіз взаємозв'язку між шорсткістю дорожнього покриття, глибиною водяного шару та коефіцієнтом тертя. Експериментальні вимірювання зчеплення коліс з поверхнею проводилися за різних погодних умов, швидкостей та навантажень. Також були змодельовані сценарії руху для різних кутів поздовжнього ухилу, типів дорожнього покриття та режимів гальмування. Крім того, результати показали, що хоча початкові інвестиції у використання новітніх матеріалів дещо вищі порівняно з традиційними технологіями, загальні витрати на утримання, ремонт та ліквідацію наслідків дорожньо-транспортних пригод значно зменшуються. Окупність інноваційних рішень спостерігається вже в середньостроковій перспективі, що підтверджує доцільність їх впровадження.

Ключові слова: аквапланування, дорожнє покриття, дренажні матеріали, пористий асфальтобетон, геосинтетика, коефіцієнт зчеплення, безпека дорожнього руху.