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RESEARCH AND PRODUCTION OF PERMEABLE CONCRETE AS A SUSTAINABLE SURFACE LAYER FOR URBAN INFRASTRUCTURES AND THE EFFECT OF MAINTENANCE METHOD ON ITS INFILTRATION CAPACITY

Nguyen Tuan Cuong[1*], Nguyen Huu Duy[2], Le Gia Khuyen[3], Tran Thi Truc Lieu[4], Vu Viet Hung[5]

Abstract – *Recently, permeable concrete has been considered one of the 'Best Management Practices in rainwater collection and cleaning. The outstanding properties of this type of concrete are its relatively high porosity (typically 15 ÷ 30% in volume) and the linking/connection of the internal pore system resulting in high water permeability and retention. However, one of the limitations to the widespread application of this eco-friendly material is the decrease of permeable capacity over time due to the clogging materials and the lack of regular maintenance. This paper performs an experimental approach for manufacturing permeable concrete that has both high water permeability and meets the strength requirement (1). At the same time, the influence of clogging sand and typical maintenance methods on the infiltration rate of permeable or pervious concrete is presented (2). Based on the literature review and obtained experimental results in this study, maintenance measures to ensure the required permeability for urban surface structures and sustainable surface water drainage are also proposed (3).*

Keywords: infiltration rate, maintenance, permeable concrete, void content.

I. INTRODUCTION

Permeable concrete (PC), also known as fine aggregate free concrete or pervious cement concrete, is an environmentally friendly construction material and has been recognized as one of the key components of sustainable development with little impact [1, 2]. PC generally consists of the following basic constituent materials: cement, water, uniform grain-size coarse aggregates, and little or no fine aggregate, resulting in large pore structures and a system of interconnected voids between aggregates. PC possesses better water permeability but has lower strength than conventional impermeable pavement [3, 4]. This sustainable surface water drainage solution reduces flooding risks and environmental pollution. Besides, the solution creates favorable conditions for infiltrating rainwater into the ground, increasing groundwater reserves, reducing the 'urban heat island' effect, and providing a suitable environment for microorganisms in the soil to grow [5–8]. However, during the long-term service of this concrete in pavement structures, the pores of PC are easily blocked by various small particles [9–12]. When residues from decomposing leaves, soil, and dust from the surrounding environment penetrate the pores, the water permeability is significantly reduced or even causes a complete blockage. For this reason, regular maintenance of the PC is necessary to maintain the permeability capacity and effectiveness of the application of this material [1, 13]. Deo et al. found that the clogging effect relatively occurs when the porosity ranges from 10 ÷ 20% and the clogging particle size is from 0.1 to 0.25 mm [10]. Similarly, another typical study on clogging materials and maintenance processes was conducted by Yuan et al. [12]. In this research, three kinds of clogging materials, ranging from 0 to 2.55 mm, were selected to demonstrate the clogging process of the pavements without cleaning and maintenance over a period of 20 years. One hundred grams

[1,2,3,4,5]University of Transport and Communications, Vietnam

*Corresponding author: hungvv_ph@utc.edu.vn

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of one kind of clogging agent were divided into 20 equal parts and a high-pressure water jet was applied to clean the specimens from the upper surface for each cycle. The experiment finished after 20 cycles. The result showed that a clay-sand mixture was the most harmful factor to PC. The study also explored that the high-pressure water-cleaning method was an effective solution to recover the permeable capacity, especially for small particles (d < 0.315 mm).

Currently, in the US, Japan and European countries, there have been many studies on the design of mixed proportions and calculation methods for this new material. Typically, ACI 522R-10 Report on permeable or pervious concrete [14] provides technical information on PC's application, design methods, materials, properties, mixture proportioning, construction methods, testing, and inspection. Meanwhile, ACI 522.1-13 Specification for pervious concrete pavement [15] covers materials, preparation, forming, placing, finishing, jointing, curing, and quality control of PC pavement. As well, Permeable Pavements [16], a new book from the American Society of Civil Engineers, is a comprehensive handbook for the proper design, construction, and maintenance of permeable pavement systems. Several PC projects and technical recommendations and guidelines on this issue have been proposed. However, the problem of optimizing the design process of the surface covered with PC is still a complex physicomechanical process that depends on the philosophies, design principles, specific local conditions, and properties of the material itself. Therefore, the development of surface structures covered with PC is still an important research area in the field of construction in many countries [17–19].

Although recently there have been several research projects on PC in Vietnam, most projects are just the first step to opening up the approach. The application conditions are still limited. In addition, the clogging phenomenon and maintenance methods for the permeability of PC have not received much attention [20–27]. A study on the influence of aggregate type and the aggregate concentration ratio on the properties of PC was carried out by Le Anh Tuan [22], and research on manufacturing and testing mechanical properties of PC with steel slag applied in the construction of traffic works (such as surface roads, sidewalks, parking spaces) was conducted by Vu Hong Nghiep [23]. Using ImageJ software to analyze sample cross-sectional images, Dong and Hanh [24] evaluated the porosity distribution according to the height of the PC sample, with different viscosities of the cement paste. This is the basis for designing the mix proportion of PC and choosing the appropriate forming mode. Recent research performed by Hong and Ha [25] has presented a design model of the entire porous concrete pavement construction that ensures not only load-bearing strength but also the high permeability and water retention. In addition, the authors have conducted a test on the field for porous concrete pavement that is light loadbearing (vehicle ≤ 2,500 kg) to evaluate the drainage efficiency of the porous concrete pavement. Some other recent experimental studies on the properties of PC using saline materials in Hai Phong Province [26] or experimental assessment of wave reduction possibility of porous concrete blocks [27] have also been conducted.

Previous experimental studies and practical experiences in developed countries show that PC applications in Vietnam are increasing for construction works, such as pavement structures, bicycle lanes, local road surfaces in residential and urban areas, and parking lots. The PC application is considered a potential and sustainable runoff water drainage solution. The application not only meets the requirements of minimum strength but also has a high water infiltration capacity. At the same time, the groundwater resources are replenished, and the urban flooding risks are minimized. However, mass-implementing a PC-covered structure faces many challenges. The structure must ensure strength and durability, enhance its ability to absorb rainwater, save cost and be easy to construct, repair and maintain. However, in Vietnam, there are no standards or technical guidelines for selecting and testing materials, construction, maintenance, and maintenance methods for PC. The objective of this paper is to successfully manufacture PC by using locally available materials that have high water permeability. In addition, the materials must satisfy the strength requirements for residential and urban infrastructure, especially for light vehicle loads and low traffic volumes (i.e., sidewalks, bicycle lanes, parking lots, and residential roads). Moreover, the study aims to investigate the influence of clogging sand and a typical maintenance method on the infiltration capacity of PC and propose maintenance measures to ensure the required permeability for urban surface structures and sustainable drainage.

II. EXPERIMENTS

A. *Materials and mix proportion*

In the scope of this paper, the PC is designed with the ratio of water/cement and aggregate/cement of 0.3 and 4.5, respectively, based on recommendations of ACI 522R-10 [14]. To introduce the internal pore structure, the coarse aggregate used in the concrete has the same particle size of 5 ÷ 10 mm and absolutely no fine aggregate (sand). Table 1 shows the basic properties of the coarse aggregate used. The aggregate particles are bonded by a cement paste and use Ordinary Portland Cement with a density of 3,150 kg/m^3 to improve the workability of the fresh concrete. Polycarboxylate-based water reducing superplasticizer is also used at a dosage of 1% by cement mass. The design mix composition of PC with a minimum designed porosity of 20% is shown in Table 2.

Table 1: Typical properties of 5 ÷ 10 mm aggregates

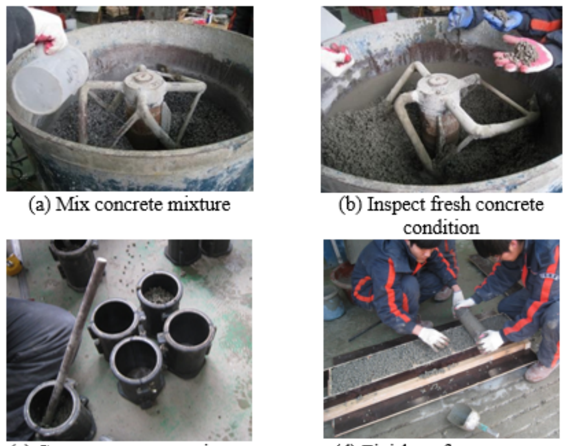
Properties	Unit	Value
Particle size	mm	5÷10
Surface	-	Flat
Particle shape	-	Angled and blocky
Bulk density	kg/m^3	1,630
Specific gravity	-	2.76
Water absorption	%	0.69
Porosity	%	40

Table 2: Mix proportion of PC (kg/m^3)

Cement	Water	5÷10 mm Aggregate	Superplasticizer
358	107	1,625	3.58 (1% by cement mass)

Concrete mixing and sample casting procedure

Concrete mixing is carried out using a vertical shaft forced concrete mixer (Figure 1a). First, the entire volume of 5 ÷ 10 mm aggregates, a part of water and superplasticizer (about 10%), and part of cement (about 10%) are mixed for 120 ÷ 180 seconds to create a uniform coating cement mortar covering aggregate particles. Then, all the remaining ingredients and mix are added for a further 180 seconds. Then, the machine is stopped and the concrete is mixed by hand and checked for uniformity and workability (Figure 1b). Finally, the mixer is run for an additional 120 seconds before pouring concrete into the molds (Figure 1c).



(a) Mix concrete mixture (b) Inspect fresh concrete condition (c) Compact concrete mixture (d) Finish surface concrete

Fig. 1: PC mixing and sample casting

The process of PC compaction is carried out by pouring concrete into the cylindrical mold of D100 x H200 mm and block mold of 200 x 200 x 125 mm, divided into two layers and compacted 25 times/layer with steel bars (length 500 mm and diameter 10 mm). After compacting each layer, the molds are lightly tap with a rubber hammer about ten times. Accordingly, 03 cylindrical samples are produced to determine porosity, permeability, and compressive strength at 28 days old, and 03 block samples are produced to evaluate the influence of clogging sand and maintenance method on the permeability of PC.

Immediately after finishing the compaction and surface finishing process, the concrete samples were covered with a layer of nylon to prevent water vapor loss and cured with a temperature of 25^{o}C and relative humidity of 50 ÷ 60% in the experimental room for 24 hours (Figure 2a). Then, the formwork was removed and the samples were cured until 14 days old at a water temperature of 25^{o}C (Figure 2b). After 14 days of curing, all samples were air-cured under the above room conditions (Figure 2c).

(a) (b) (c)

Fig. 2: PC curing regime

B. Typical physical and mechanical properties tests

Density and void content of hardened PC is determined according to the ASTM C1754/C1754M-12 Standard Test Method for Density and Void Content of Hardened Pervious Concrete [28] as follows:

Density of hardened PC (γ [kg/m^3]):

$$\gamma = \frac{K \times A}{D^2 \times L} \quad (1)$$

The porosity (θ[%]) of PC is determined based on the difference between the total volume of the sample and the volume change when the sample is immersed in water according to the following formula:

$$\phi = \left[1 - \left(\frac{K_1 \times (A - B)}{\rho_W \times D^2 \times L}\right)\right] \times 100 \quad (2)$$

Where:

A = Dry mass of specimen (g)

B = Underwater mass of specimen (g)

D = Average diameter of specimen (mm)

L = Length (or height) of specimen (mm)

K_1 = 1,273,240 (in SI units)

ρ_w = Density of water (kg/m^3)

The 28-day-old compressive strength (R_n [MP_a]) of the concrete sample is determined according to the ASTM C39/C39M-17b [29] Standard on the test to determine the compressive strength of the cylindrical concrete sample D100 × H200 mm:

$$R_n = \frac{4000 \times P_{max}}{\pi \times D^2} \quad (3)$$

Where:

P_{max} = destructive compressive load of the sample (kN)

C. Infiltration test and influence of clogging sand materials and maintenance method on the infiltration rate

Permeability or infiltration capacity is one of the crucial properties of PC. However, during use in practice, the pores of PC are easily blocked by various small particles, thus the water permeability is significantly reduced, even causing a complete blockage. In this study, the infiltration rate of the cylindrical sample of D100 x H150 mm and the block sample of 200 x 200 x 125 mm is calculated, with the water-level height varying in the range of 10 ÷ 15 mm from the top surface of the sample (Figure 3). The water level is almost unchanged, similar to the standard ASTM C1701/C1701M-17a [30] on the standard test method for the Infiltration rate of in-place pervious concrete.

$$I = \frac{K_2 \times M}{D^2 \times 3600 \times t} \quad (4)$$

Where:

I = Infiltration rate (mm/s)

M = Mass of infiltrated water (kg)

D = Inner diameter of infiltration pipe (mm)

t = Time required for a measured amount of water to infiltrate the specimen (s)

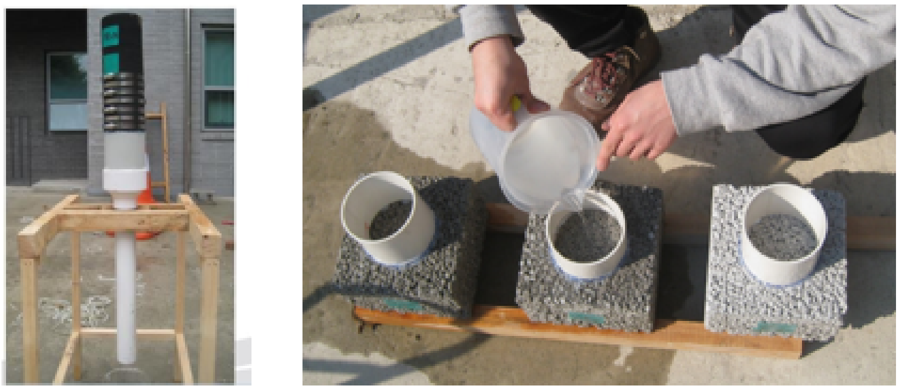
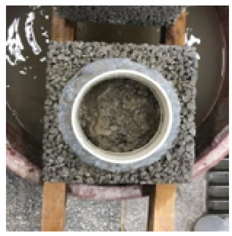


Fig. 3: Test to determine the infiltration rate with a water level height of 10 ÷ 15 mm for cylindrical samples (left) and block samples (right)

K_2 = 4,583,666,000 (in SI units)

Based on the trial tests and reference of Yuan et al. [12], the authors evaluated the effect of clogging materials and the effectiveness of the maintenance method of PC through infiltration tests. Infiltration tests were performed by accumulating sand with a grain size of less than 0.15 mm (assuming the sandy soils) with a content of four times x 8.3 g/l water flows through the block sample (modeling the clogging process of the pavements for areas that are not regularly maintained and cleaned) for three cycles as shown in (a) and (b) of Figure 4. After each cycle, maintenance with pressured water hose and vacuum is performed as in (c) and (d) of Figure 4 to restore the permeability capacity of the PC.

(a) Spread sand on the surface of the sample



(b) Pour water flow through the sample

(c) Apply pressured water

(d) Vacuum sample surface

Fig. 4: Effect of clogging sand and maintenance measure on PC infiltration

III. EXPERIMENTAL RESULTS AND PROPOSALS

A. Some typical physical and mechanical properties of permeable concrete

The average density and porosity of the hardened cylindrical concrete samples were determined to be 2,068 kg/m^3 and 22.2%, respectively. According to the experimental results, the compressive strength of PC at 28 days old in this study is from 12 to 18 MPa. It can be seen that the values obtained in this paper are within the common range when comparing references with other previous studies [1, 2, 14].

B. Infiltration rate and the effect of clogging sand material and maintenance method on its permeability capacity

According to the results, PC has an infiltration rate of about 1.62 ÷ 4.23 mm/s, with a porosity of 22.0 ÷ 22.3%. Although the porosity of the samples is close to the same, there is a relatively large difference in the infiltration rate. The infiltration or permeability of PC is affected when the pores in the sample are not connected continuously or distributed separately. In other words, the permeability or the infiltration rate of PC depends on the connectivity of the pores rather than the porosity value [31].

Moreover, Table 3 shows the test results for the effect of pore-clogging due to sand and the maintenance measures applied to maintain the permeability capacity of the PC. The initial average infiltration rate of the block sample is 1.72 mm/s before the clogging test, decreasing to 0.77 mm/s after the first cycle, and recovering to 1.11mm/s after the maintenance measure is applied. It can be seen that the infiltration rate of the PC sample is reduced by 35% compared to the initial value in the first cycle. After completing the 2nd and 3rd cycles, the infiltration rate is 0.65 and 0.68 mm/s, respectively. These values reach 38% and 40% of the initial value, respectively. Experimental results show that vacuum cleaning and pressure watering are effective solutions for maintaining and restoring the permeability capacity of PC. Similar results were also observed in other studies [1, 32]. However, further experiments and studies are needed to accurately evaluate the effect and effectiveness of the maintenance measure on the infiltration of PC.

C. Proposing maintenance methods to ensure the required permeability for urban surface structures using PC

The main goal of maintenance is to prevent the PC surfacing layer from becoming clogged with fine particles. Therefore, the surface must be cleaned and restored regularly when clogged to ensure the designed permeability.

Based on the experimental findings and results above, it can be divided into maintenance regimes for PC surface layers as follows:

- Routine maintenance: monthly visual inspection of the surface layer to make sure the textured surface is clean and well-drained during and after rain. In places where puddles form, it is a sign that the coating surface requires cleaning. Periodic cleaning and maintenance should be done with a vacuum cleaner or road sweeper every 06 months [33]. If the pavement surface has become so clogged that vacuum sweeping cannot restore permeability, a higher level of treatment may be required. At that time, it is possible to apply the technique of washing the PC surface with clean water at low pressure, followed by the use of a vacuum cleaner as presented in this paper.

- Unscheduled maintenance: for areas that are not regularly maintained and cleaned as seen in this experiment, the PC surface layer is easily clogged with sediment particles over time. For example, the infiltration rate of the PC is reduced by 55% compared to the initial value in the first cycle. Usually, the average infiltration rate is reduced by 25% from the initial value [33]. In this case, the best maintenance is a combination of water pressure washing (pressure ranging from 0.860 MPa to 3.450 MPa) and simultaneous vacuuming. However, avoid washing the surface with too high water pressure as this will reduce the adhesion of cement and aggregate, causing dislodgement of the surfacing material. On the other hand, the high-pressure water can push the sediment particles deep into the underlined layers.

IV. CONCLUSIONS

Based on the laboratory results on the fabrication of permeable concrete, the evaluation of the influence of sandy soil causing pore-clogging, and the effectiveness of a typical maintenance measure on the permeability capacity of the PC, the following conclusions can be drawn.

The designed mix proportion of permeable concrete containing a uniform aggregate size of 5 ÷ 10 mm with the ratio of water/cement and aggregate/cement of 0.3 and 4.5, respectively, contributes to both high water permeability (infiltration rate of 1.62 ÷ 4.23 mm/s, porosity of 22.0 ÷ 22.3%), sufficient strength requirement (12 ÷ 18 MPa) and can be used to replace the traditional cement concrete surface coating (normally characterized by high density and low porosity concrete).

The infiltration rate of PC can be restored to a certain proportion after the permeability is reduced due to sandy soil particles of less than 0.15 mm and then cleaned by a vacuum cleaner and pressured water. However, completely restoring the infiltration rate to the original is very difficult. Therefore, there is a need for further

Table 3: The change of infiltration rate according to the accumulation of clogging sand and the influence of maintenance measures

Testing cycle		Number of times spreading sand on the sample surface				
		1	2	3	4	5
1st cycle	Infiltration rate (mm/s)	1.72	1.42	1.21	0.93	0.77
	Ratio (%)	100	83	70	54	45
2nd cycle	Infiltration rate (mm/s)	1.11	0.93	0.83	0.73	0.65
	Ratio (%)	65	54	48	42	38
3rd cycle	Infiltration rate (mm/s)	0.98	0.81	0.78	0.72	0.68
	Ratio (%)	57	47	45	42	40

research to develop more effective permeable concrete and maintenance methods. In addition, maintenance measures are proposed to ensure the required permeability of urban surfacing structures that meet sustainable water drainage requirements and minimize the adverse effects of heavy rainfall and urbanization.

REFERENCES

[1] Alalea K, Hong SW, Christopher RC. Clogging in permeable concrete: A review. *Journal of Environmental Management*. 2017;193: 221–233. https://doi.org/10.1016/j.jenvman.2017.02.018.

[2] Avishreshth S, Prasanna VS, Krishna PB. A review of sustainable pervious concrete systems: Emphasis on clogging, material characterization, and environmental aspects. *Construction and Building Materials*. 2020;261: 120491. https://doi.org/10.1016/j.conbuildmat.2020.120491.

[3] Chindaprasirt P, Hatanaka S, Chareerat T, Mishima N, Yuasa Y. Cement paste characteristics and porous concrete properties. *Construction and Building Materials*. 2008;22(5): 894–901.

[4] Viet-Hung Vu, Bao-Viet Tran, Ba-Anh Le, HoangQuan Nguyen. Prediction of the relationship between strength and porosity of pervious concrete: A micromechanical investigation. *Mechanics Research Communications*. 2021;118: 103791. https://doi.org/10.1016/j.mechrescom.2021.103791.

[5] Vu Thai Son, Vu Viet Hung, Nguyen Tuan Cuong, Truong Dinh Thao Anh, Tran Bao Viet. Predicting the permeability of pervious concrete based on a data-driven approach. [Xây dựng công thức dự báo hệ số thấm của bê tông rỗng dựa trên định hướng dữ liệu]. *Transport and Communications Science Journal [Tạp chí Khoa học Giao thông Vận tải]*. 2022;73(2): 176–88. https://doi.org/10.47869/tcsj.73.2.7.

[6] AlShareedah O, Nassiri S. Pervious concrete mixture optimization, physical, and mechanical properties and pavement design: A review. *Journal of Cleaner Production*. 2021;288: 125095. https://doi.org/10.1016/j.jclepro.2020.125095.

[7] Debnath B, Sarkar PP. Pervious concrete as an alternative pavement strategy: a state-of-the-art review. *International Journal of Pavement Engineering*. 2020;21(12): 1516–1531. https://doi.org/10.1080/10298436.2018.1554217.

[8] Singh A, Sampath PV, Biligiri KP. A review of sustainable pervious concrete systems: Emphasis on clogging, material characterization, and environmental aspects. *Construction and Building Materials*. 2020;261: 120491. https://doi.org/10.1016/j.conbuildmat.2020.120491.

[9] Lin W, Park DG, Ryu SW, Lee BT, Cho YH. Development of permeability test method for porous concrete block pavement materials considering clogging. *Construction and Building Materials*. 2016;118: 20–26.

[10] Deo O, Sumanasooriya M, Neithalath N. Permeability reduction in pervious concretes due to clogging: experiments and modeling. *Journal of Materials in Civil Engineering*. 2010;22(7): 741–751. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000079.

[11] Haselbach L. Potential for clay clogging of pervious concrete under extreme conditions. *Journal of Hydrologic Engineering*. 2010;15(1): 67–69. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000154.

[12] Yuan J, Chen X, Liu S, Li S, Shen N. Effect of water head, gradation of clogging agent, and horizontal flow velocity on the clogging characteristics of pervious concrete. *Journal of Materials in Civil Engineering*. 2018;30(9): 04018215. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002410.

[13] Hein MF, Dougherty M, Hobbs T. Cleaning methods for pervious concrete pavements. *International Journal of Construction Education and Research*. 2013;9(2): 102–116. https://doi.org/10.1080/15578771.2011.649886.

[14] ACI Committee 522. *ACI 522R-10 Report on Pervious Concrete*. American Concrete Institute; 2010.

[15] ACI Committee 522. *ACI 522.1-13 Specification for Pervious Concrete Pavement*. American Concrete Institute; 2013.

[16] Permeable Pavements Task Committee. *Permeable Pavements*. American Society of Civil Engineers. 2015. https://doi.org/10.1061/9780784413784.

[17] Păcesilă, Mihaela, David Butler, John W. Davies. Theoretical and empirical researches in urban management. *JSTOR*. 2012;7(1): 88–91. http://www.jstor.org/stable/24873312.

[18] Brattebo BO, Booth DB. Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Research*. 2003;37(26): 4369–4376. https://doi.org/10.1016/S0043-1354(03)00410-X.

[19] Zhou Q. A review of sustainable urban drainage systems considering the climate change and urbanization impacts. *Water Research*. 2014;6(4): 976–992. https://doi.org/10.3390/w6040976.

[20] Nguyen Van Chanh, Nguyen Hoang Duy, Hoang Pham Nam Huan. Porous concrete technology for roadside construction and public works. [Công nghệ bê tông xốp thi công ven đường và công trình công cộng]. *Vietnam Journal of Construction [Tạp chí Xây dựng]*. 2006;3: 24–29.

[21] Le Thai Binh, Nguyen Van Son. Research on the application of permeable concrete in construction works in Vietnam. [Nghiên cứu ứng dụng bê tông thấm nước trong các công trình xây dựng ở Việt Nam]. *Collection of annual scientific conference, Thuyloi University [Trong: Tuyển tập hội nghị khoa học thường niên, Trường Đại học Thuỷ lợi]*. 2013; 51–53.

[22] Le Anh Tuan. Study on the influence of aggregate type and cement/aggregate ratio on the properties of porous concrete. [Nghiên cứu ảnh hưởng của tổng hợp loại và tỉ lệ xi măng/cốt liệu đến tính chất của bê tông xốp]. *Vietnam Journal of Construction [Tạp chí Xây dựng Việt Nam]*. 2016;8: 38–41.

[23] Vu Hong Nghiep, Bui Nguyen Thanh, Nguyen Dinh Hung. Research on using steel slag to replace coarse aggregate to make porous concrete for the construction of some transportation works. [Nghiên cứu sử dụng xỉ thép thay thế cốt liệu thô làm bê tông xốp để xây dựng một số công trình giao thông]. *Transport and Communications Science Journal [Tạp chí Khoa học Giao thông Vận tải]*. 2016;23: 93–97.

[24] Nguyen Van Dong, Pham Huu Hanh. Effect of binder viscosity on the structure of pervious concrete. [Ảnh hưởng của độ nhớt hồ chất kết dính tới cấu trúc của bê tông rỗng thoát nước]. *Journal of Materials & Construction [Tạp chí Vật liệu & Xây dựng]*. 2021;1: 41–45.

[25] Nguyen Thi Hong, Le Thanh Ha. Research on porous concrete pavement construction for sustainable drainage. [Nghiên cứu kết cấu mặt đường bê tông xi măng rỗng có khả năng thoát nước mặt theo hướng phát triển bền vững]. *Journal of Materials & Construction [Tạp chí Vật liệu & Xây dựng]*. 2022;12(02): 53–63.

[26] Nguyen Tuan Trung, Nguyen Van Dong. Experimental study of some properties of pervious concrete using saline materials. [Nghiên cứu thực nghiệm một số tính chất của bê tông rỗng sử dụng vật liệu nhiễm mặn]. *Journal of Materials & Construction [Tạp chí Vật liệu & Xây dựng]*. 2021;11(05): 42–48.

[27] Le Hai Trung, Nguyen Van Tuan, Tran Thanh Tung, Dang Thi Linh, Nguyen Truong Duy, Bach Duong. Experimental assessment of wave reduction possibility of porous concrete blocks. [Thí nghiệm đánh giá khả năng giảm sóng của cấu kiện bê tông rỗng]. *Journal of Science and Technology in Civil Engineering [Tạp chí Khoa học Công nghệ Xây dựng]*. 2021;15(3V):44–54.

[28] ASTM Standard C1754/C1754M-12. *Standard Test Method for Density and Void Content of Hardened Pervious Concrete*. Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, USA; 2012.

[29] ASTM Standard C39/C39M-17b. *Standard on the test to determine the compressive strength of the cylindrical concrete sample*. ASTM International, West Conshohocken, PA, USA. 2017.

[30] ASTM Standard C1701/C1701M-17a. *Standard Test Method for Infiltration rate of In Place Pervious Concrete*. West Conshohocken, PA, USA: ASTM International; 2017.

[31] Sonebi M, Bassuoni M, Yahia A. Pervious Concrete: Mix Design, Properties and Applications. *RILEM Technical Letters*. 2016;1: 109–115. https://doi.org/10.21809/rilemtechlett.2016.24.

[32] Hein MF, Dougherty M, Hobbs T. Cleaning methods for pervious concrete pavements. *International Journal of Construction Education and Research*. 2013;9(2): 102–116. https://doi.org/10.1080/15578771.2011.649886.

[33] National Ready Mixed Concrete Association. *Pervious Concrete Pavement Maintenance and Operations Guide*; 2006. https://www.perviouspavement.org/downloads/pervious_maintenance_operations_guide.pdf

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