Committee report Study committee on establishment of construction standards and quality assurance system for performance-based design of porous concrete

Shigemitsu HATANAKA*[1], Takahisa OKAMOTO*[2], Satoshi KAJIO*[3]・Minoru KUNIEDA*[4], Naoki MISHIMA*[5], Takashi HIRAIWA*[6]

Abstract: Porous concrete can be designed so as to have various performances such as being water permeable and allowing vegetation growth and is thus expected to be useful materials for constructing social infrastructures, such as road pavement, that would play important roles not only in protecting the environment but also in preventing disasters such as during storms. However, there have been no construction standards or quality assurance standards established. The study committee on establishment of construction standards and quality assurance system for performance-based design of porous concrete has aimed to summarize study results in the past, conducted experimental studies toward quality assurance, and presented performance-based design guidelines (draft) for realizing performance-based design and manufacture and construction guidelines (draft) and acted toward establishment of a quality assurance system.

Keywords: Porous concrete, pervious concrete, performance-based design guidelines, manufacture and construction guidelines, quality assurance, pavement, revetment, slope

1. Introduction

Porous concrete has continuous voids or pores within and can be designed to have various performances such as being water permeable and retentive and allowing vegetation growth. It is thus expected to be useful materials for constructing social infrastructures that would play important roles not only in protecting the environment but also in preventing disasters such as during storms. However, there have been no construction standards or quality assurance standards established in Japan; and the lack of such standards that are indispensable for stable manufacture and resultant performance-based design is likely to be the main cause that has impeded sound spread of porous concrete.

In countries outside Japan, for example in the US, generalization has been promoted by using a uniform and standardized name of pervious (water-permeable) concrete and establishing ASTM standards. The ISO/TC71/SC1 committee started establishing standards on testing methods of porous (mainly water-permeable) concrete mainly by Korean members. In Japan, Japan Concrete Institute (JCI) formed a study committee on establishment of methods for designing and constructing porous concrete (chair: Motoharu TAMAI, Professor

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of Kinki University (at that time)) in 2001 and 2002, which acted, reflecting the world leading research activities of Japan. However, it has dispatched little information to the rest of the world and only issued an abstract of the committee report in English.

The main objectives of the study committee on establishment of construction standards and quality assurance system for performance-based design of porous concrete (hereinafter referred to as the “committee”) include:

1) To survey and reorganize past study results in and outside Japan, organize the basic references for performance-based design, and classify and organize urgent and future study topics,

2) To conduct experimental studies toward quality assurance systematically and jointly as a committee, and

3) To present performance-based design guidelines (draft) and manufacture and construction guidelines (draft) that meet the technical level of Japan to actualize performance-based design of porous concrete.

The members of the committee include not only researchers in the field of civil engineering, architecture and chemistry but also engineers in charge of ordering, manufacture and construction. During the first year, the committee established working groups on quality and performance, job site, and products to mainly investigate matters required in the practical and implementation stages. In the second year, performance-based design WG, manufacture and construction WG and quality assurance WG worked on preparation of performance-based design guidelines (draft) and manufacture and construction guidelines (draft) also conducted experiments common and related to quality control. The constitution of the committee in the second year is shown in **Table-1**. The common experiments were conducted jointly with the POC study committee of the Chubu Branch of JCI. The report is overviewed below along with the table of contents.

Table-1 Constitution of the committee

Chairman of Committee	Shigemitsu HATANAKA	MIE UNIVERSITY
Vice Chairman of Committee	Takahisa OKAMOTO	RITSUMEIKAN UNIVERSITY
Secretary Genera of Committee	Satoshi KAJIO	TAIHEIYOU CEMENT CORPORATION
Secretary of Committee	Minoru KUNIEDA	GIFU UNIVERSITY
	Takashi HIRAIWA	MEIJYO UNIVERSITY
	Naoki MISHIMA	MIE UNIVERSITY
Committee Member	Kazuma ASANO	WATANABE SATO CO., LTD.
	Mitsuo IGAMI	TAIHEIYO PRECAST CONCRETE INDUSTRY CO.,LTD.
	Masao ISHIDA	TAIHEIYO CEMENT CORPORATION
	Yasuji ITOU	NATIONAL FEDERATION OF READY-MIXED CONCRETE INDUSTRIAL ASSOCIATIONS

	Atsushi UENO	TOKYO METROPOLITAN UNIVERSITY
	Mamoru KAGATA	KAJIMA ROAD CO., LTD.
	Hiroshi KATAHIRA	PUBLIC WORKS RESEARCH INSTITUTE
	Tatsuya KIMURA	JAPAN LANDCARE TECHNOLODIES CO., LTD.
	Toshikatsu SAITOU	NIHON UNIVERSITY
	Katsuji SUGIMOTO	HOSHIYAMA KENSETSU CO., LTD.
	Kazuhisa TAKAYAMA	SUMITOMO OSAKA CEMENT CO., LTD.
	Motoharu TAMAI	KINKI UNIVERSITY
	Ken TSURUTA	MATERRAS OUME KOUGYOU CORPORATION
	Yoshiaki NARITA	KYOWA CONCRETE INDUSTRY CO., LTD.
	Takayuki FUMOTO	KINKI UNIVERSITY
	Kunio YANAGIBASHI	TAKENAKA CORPORATION
	Yoshihiko TAKADA	HANSHIN EXPRESSWAY COMPANY LIMITED
	Yoshitaka ISHIKAWA	ELECTRIC POWER DEVELOPMENT CO., LTD.
Cooperate Member	Masahiro HYOUDOU	TOTTORI UNIVERSITY
	Naho TAKEDA	NATIONAL INSTITUTE OF TECHNOLOGY, AKASHI COLLEGE
	Takuya JYUMONJI	TAIHEIYO CEMENT CORPORATION
	Kazunori AOKI	INABU READY-MIXED CONCRETE CO., LTD.
	Zhang RIHONG	WAKO CONCRETE CO., LTD.
	Sinya NAKA	RITSUMEIKAN UNIVERSITY
	Chindaprasirt, P.rinya	KHON KAEN UNIVERSITY, THAILAND
	Maogang ZHANG	WUXI CITY COLLEGE VOCATIONAL TECHNOLOGY, CHINA
	Gun-Cheol LEE	KOREA NATIONAL UNIVERSITY OF TRANSPORTATION, KOREA

2. Research trends and issues of porous concrete in these 10 years in documents in and outside Japan

2.1 Overview of research trends

The committee surveyed the research trends in and outside Japan after the JCI committee on porous concrete (2001 and 2002). Documents collected were those of which the full text was available on the web, etc. The number of documents collected was 587 in Japan and 58 in other countries. Besides these, American Concrete Institute (ACI) summarized a committee report on pervious concrete in 2011 [1].

Changes in the number of papers published are shown in **Fig.-1**. Papers published in Japan showed a decreasing trend, while papers outside Japan was increasing. This is mainly attributable to the availability of papers although the absolute number of papers differed between those in and outside Japan. **Fig.-2** shows the number of papers for each target purpose of using porous concrete. In Japan, a wide variety of purposes have been investigated, while most studies outside Japan focused on pavement. This was likely because recognition of porous concrete outside Japan has mainly focused on its water permeability, the property of being pervious (Pervious Concrete).

2.2 General characteristics

2.2.1 Void content and mechanical properties

There have been many research reports on void content and mechanical properties. Research institutes and companies have established their own technologies for setting the target void content and strength and for manufacturing concrete that almost satisfy the targets. However, researches have been insufficient on classification of void content, theoretical background, effects of placing and curing methods, and other precise aspects. They are likely to be future topics.

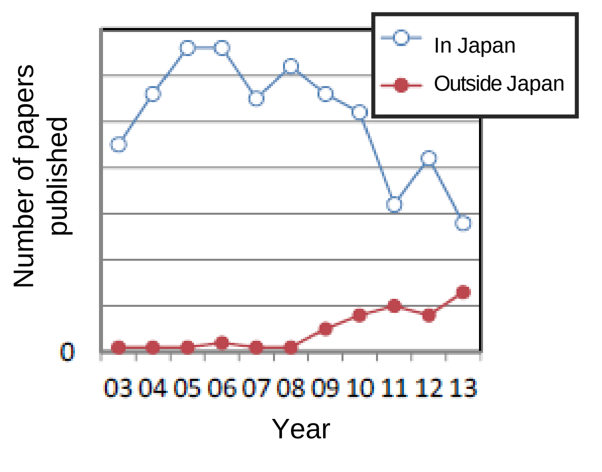


Fig.-1 Changes in the number of papers published

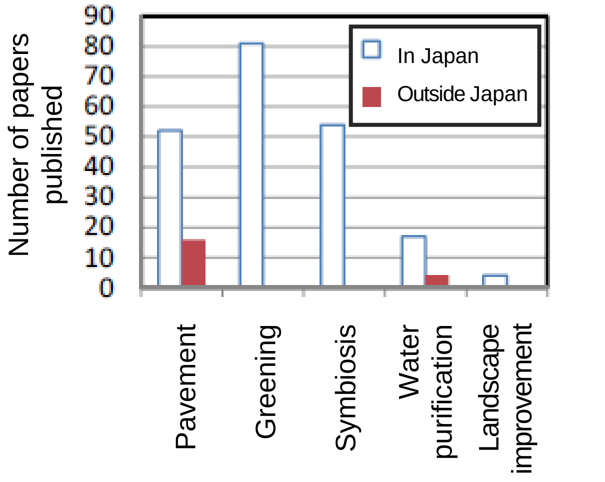


Fig.-2 Number of papers published for each purpose of use

2.2.2 Water permeability

Technologies have almost been established for setting target water permeability of porous concrete and for manufacturing concrete that satisfies the target. However, there are several problems left, including that 1) the coefficient of permeability, which serves as an index value, differs depending on test condition, and 2) the permeability of actually constructed concrete decreases in a time sequential manner due to clogging. The former requires establishment of a reproducible and simple testing method, and the latter needs establishment of a method for restoring the concrete from clogging.

2.2.3 Durability

(1) Repeated drying and wetting and freezing damage

There have been cases in which repeated drying and wetting did and did not cause deterioration. The difference of the result is estimated to be attributable to differences in the physical properties of aggregates, and thus the relationship needs to be organized between such material properties and resistance to damage by alternate wetting and drying. There have also been reports that mentioned that the concrete deteriorated by repeated drying and wetting in a test that followed the drying and wetting test method (draft) but did not deteriorate in a test that reproduced the actual environment, requiring the scope of the proposed test method (draft) and evaluation standards to be investigated.

On freezing and thawing, establishment of a unified accelerated test method is an issue. According to investigation of porous concrete under exposed environments, river revetment blocks had relatively high freeze-thaw resistance, but porous concrete pavement where anti-freezing agent would be sprayed had undergone severe deterioration. The durability and applicability of porous concrete pavement in cold area is an important topic of investigation.

(2) Other durability performances

Performances have been somewhat investigated on leaching of calcium by fresh water and/or seawater, fatigue properties and effects of plants. On the other hand, abrasion, effects of anti-freezing agent, clogging, and alkali aggregate reaction need to be further investigated experimentally in order to understand the mechanisms and investigate testing methods for assessing the durability.

2.2.4 Materials used

In various studies on use of recycled materials, fiber-reinforced materials, and new materials in porous concrete, it has been reported that the materials could improve various performances of the concrete and have been effective. Establishment of methods is desired for selecting materials and designing mix proportion so that the resultant concrete would satisfy the required performances for the target purpose.

2.3 Use

2.3.1 Pavement

Porous concrete pavement has already been implemented as a major use of porous concrete. However, the durability and surface performances of porous concrete pavement have only been evaluated for a period not exceeding 10 years and need to be assessed for longer periods. On clogging of voids, technologies are awaited for maintaining and restoring the functions.

2.3.2 Greening

In order to use porous concrete to grow plants, several big issues still remain to be solved, such as lowering the pH and controlling erosion of dressed soil and water retentiveness of the planting base. An index should also be defined to quickly and effectively evaluate rooting of plants. It is also desired to accumulate study results on durability of concrete against forces imposed from inside by growing plant roots.

2.3.3 Symbiosis

Porous concrete has been reported to be effective for building fish reef, seaweed beds and water channels. It is important in future to investigate appropriate void content and void sizes of porous concrete that aims for symbiosis based on survey results of strength characteristics, persistence of fish gathering performances and durability.

2.3.4 Purification and adsorption

Effects of mix proportion and conditions of use on the purification and adsorption performances of porous concrete have not been clarified. Further investigation is awaited to incorporate them in performance-based design of porous concrete.

2.3.5 Temperature characteristics

There is no clear target value, such as of surface temperature, about thermal performances required to porous concrete slab. It is necessary to continue data accumulation, determine the direction of handling transfer of sensible heat, identify the required temperature characteristics, and investigate material constitution and mix proportion for satisfying the required performances.

2.3.6 Sound-absorption characteristics

Sound-absorption characteristics of porous concrete have been relatively widely reported, including normal incident sound absorption coefficient measurements and measurements of noise level by traveling vehicles. Deterioration of sound-absorption characteristics has been reported for highway pavement in service. In the discussion toward standardization, it will be important to set target performances including stability of the performances and establish evaluation methods.

2.4 Trends in oversea countries (Asian countries)

2.4.1 China

In China, pervious pavement has been constructed in Beijing Olympic Park and Shanghai Expo Park. However, there are no standards on design, construction or testing method. Basic studies on porous concrete, such as on its mechanical properties and durability, are still insufficient. Further research and development are expected.

2.4.2 Korea

Recently in Korea, most researches focus on application of industrial byproducts and construction wastes. Regarding purposes, secondary products such as revetment blocks are widely seen. Today, ISO TC71 SC1 is preparing standards for testing pervious concrete; and Korea is planning to establish KS (Korean Industrial Standards) that copes with the ISO. Various organization standards are also being constructed.

2.4.3 Thailand

In Thailand, studies and implementation of porous concrete are still in the initial stage.

Since the introduction of the technology in 2006, research papers have been published. Some cement companies are already selling porous concrete products. However, it is still difficult to find construction machines for porous concrete and experienced construction engineers, and thus the production is not large.

3. Examples of designing cast-in-place porous concrete for each purpose

3.1 Overview of activities

This section summarizes a survey on examples of conventional cast-in-place porous concrete, porous concrete technologies for satisfying required performance levels and requirements, points to note for satisfying the required performances, and issues concerning maintenance of the concrete. **Figure 3** shows the concept of porous concrete for performance-based design. Irrespective of cast-in-place concrete or concrete product, the necessary performance levels can be properly grasped by clarifying performances required by consumers as performances of porous concrete structure.

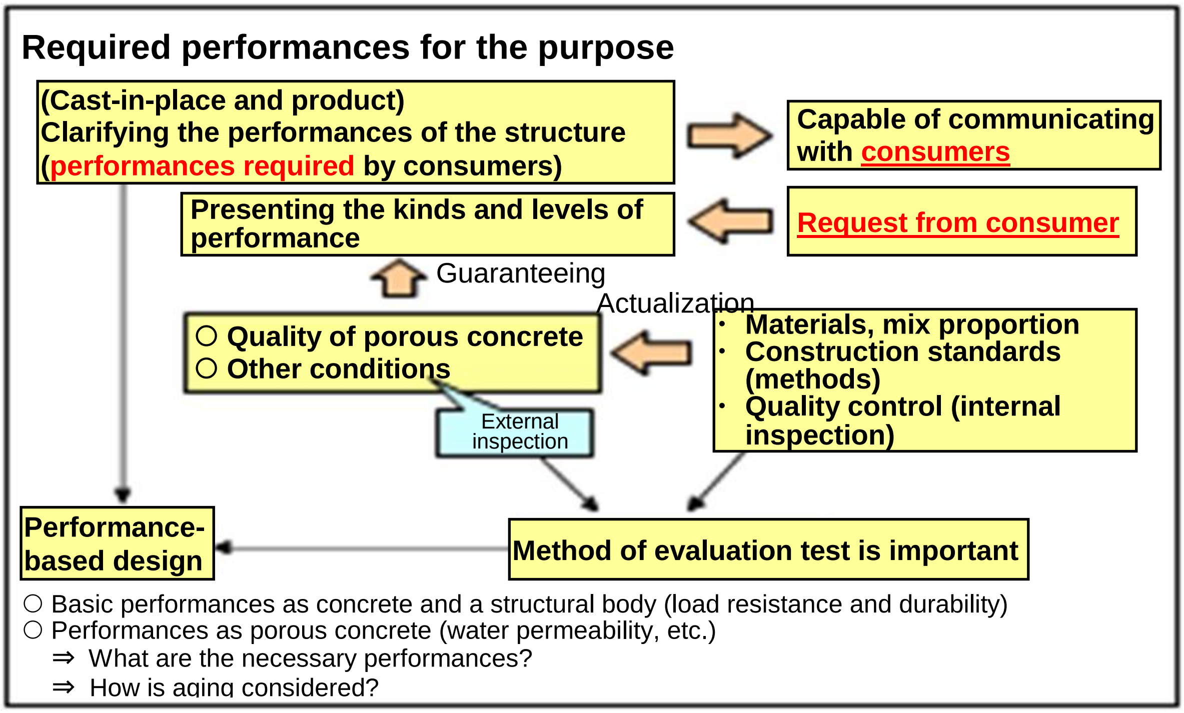


Fig.-3 Concept of concrete for performance-based design

3.2 Performances as pavement

3.2.1 Water permeability

As performances required to pervious porous concrete pavement, Pavement Design Construction Guideline prescribes standard quantity of water drainage. For using porous concrete for surface course, a coefficient of permeability of at least 1×10^{-2}cm/sec is required [2]. Porous concrete on surface course is suspected for losing water permeability along passage of time due to clogging of voids by dust, sand, dirt, etc. To maintain and restore porous concrete from permeability loss during service, methods, timing and frequency of restoration needs to be investigated for each site of construction.

3.2.2 Water retention

Cast-in-place porous concrete pavement is pervious pavement that can retain rainwater, which seeps directly from the surface of the pavement. The permeable subgrade type stores water temporarily in the voids of the base course and expects the water to penetrate to the subgrade. It is designed from the amount of voids in the pavement body and the saturated coefficient of permeability of the subgrade soil. The temporarily storing type is used when the subgrade cannot be expected to be pervious. It stores rainwater temporarily in the pavement body, drains and discharges the water from drain pipes installed on the subgrade, and controls, reduces and/or delays discharge of rainwater combined with water storage facility. Thus, expected effects of the water retention performance of porous concrete include controlling outflow to rivers and reducing loads to sewage and road drainage facilities.

3.2.3 Reduction of tire-pavement noise

Porous concrete pavement is believed to reduce tire-pavement noise by voids mitigating the explosive noise by tire treads and further absorbing fricative noise. Required performance to newly constructed porous concrete is in some cases 90dB, which is about 3dB lower than ordinary asphalt concrete pavement.

3.2.4 Thermal performances

There has been no study on the effects of materials and void content of porous concrete on its thermal performances. Because thermal performances are greatly affected by environmental conditions and color, it is likely difficult to set the conditions of porous concrete that satisfy required thermal performances at the moment.

3.3 Uses other than pavement

3.3.1 Draining (for protecting slope)

To use porous concrete as drainage and protection works of slope, it is required to be capable of effectively and quickly discharging retained water while controlling outflow of soil (natural ground). Therefore, it must have water permeability, filtration effect and sufficient strength as a structure. Previous porous concrete is thus needed that satisfies the required performances determined based on investigations on the strength, durability, abrasion resistance, freeze-thaw resistance, etc. of the structure and stability of the slope.

3.3.2 Greening (symbiosis and vegetation)

Environmental symbiosis in construction, particularly symbiosis with plants, is increasingly considered when constructing concrete structure also from the viewpoint of “biodiversity”, which recently became an important social issue. A method of fusing greenery and structure toward coexistence of an infrastructure or a building and organisms is a technology that is based on porous concrete. Although applications have decreased these years, porous concrete has been implemented mainly for a number of river revetments. When greening performance is added to porous concrete, the specifications to be prescribed vary greatly especially on the void content and dimensions of voids of porous concrete depending on whether there is a water supply from the back side. For using porous concrete as vegetation bed in a place where there is usually no water supply, a measure should be investigated such as filling water retentive agent in voids, dressing soil on the surface and using irrigation facility, when necessary.

4. Organization of the present states of porous concrete products and issues

4.1 Overview of activities

Various porous concrete products have been developed and implemented, such as interlocking blocks, greening blocks, fish reef blocks, sound absorption blocks and water purification blocks (See **Table-2**). In this section, actual uses of various porous concrete products in recent years are summarized, and results of a questionnaire survey conducted to extract relevant issues reports and collect information toward solving problems related to porous concrete are reported.

Table-2 Overview of porous concrete products

<table>
<tr><td>Kind of porous concrete product</td><td>Main physical properties of porous concrete</td></tr>
<tr><td>Block brick</td><td rowspan="3">・Grow plants (greening)
・Control the height of plants (greening control)
・Create habitats for organisms (biodiversity)</td></tr>
<tr><td>Foot protection block</td></tr>
<tr><td>Retaining wall (vertical, reversed trapezoid)</td></tr>
<tr><td>Interlocking block</td><td rowspan="4">・Pass water (pervious)
・Store water (water retentive)</td></tr>
<tr><td>Pervious concrete plate</td></tr>
<tr><td>Water gathering basin (round, square)</td></tr>
<tr><td>Gutter, U-shaped ditch</td></tr>
<tr><td>Water purification block</td><td>・Purify water</td></tr>
<tr><td>Acoustical board</td><td>・Absorb noise</td></tr>
<tr><td>Landscape improvement block, surface cover block</td><td>・Harmonize the appearance with the surrounding scene</td></tr>
</table>

4.2 Overview of the questionnaire survey

In the questionnaire survey, porous concrete products manufactured by companies were surveyed.

Characteristically, it is possible to add various performances to porous concrete. The committee surveyed 1) how manufacturers performed control in order to add such performances, 2) technical issues and needs at each stage of manufacturing porous concrete products, including material procurement, designing, construction and maintenance, and 3) issues and needs related to standards. Sixteen companies answered the questionnaire consisting of 19 questions.

4.3 Analysis of the results of the questionnaire survey and future issues

The questionnaire survey revealed the following issues:

・Design that uses compressive strength and void content has spread, but indices for other performances are still immature.

- In-situ testing methods (control methods) need to be established.
- Methods for regulating and controlling changes in void content, etc.
- Model for evaluating durability and deterioration model
- Method for evaluating freeze-thaw resistance
- Degradation of functions by clogging
- Development of new purpose (such as controlling luminosity)
- Revision of design guidelines (manual)
- Method for evaluating the performances of composite member
- Appeal to society (manager and users)

5. Testing methods for quality evaluation

5.1 Introduction

Outside Japan, ASTM has already established several testing standards for pervious concrete. ISO is also preparing standards for testing permeability and void content. Testing standards are more advanced outside Japan than in Japan. Therefore, it is urgent to establish domestic standards in Japan and dispatch the information by having a perspective of exporting Japanese technologies about porous concrete in the future.

5.2 In-situ testing methods

Of all in-situ testing methods implemented on porous concrete, the largest number is for testing pavement. Seventeen testing methods have been reported including in-situ permeation test (See **Photo-1**). Most of these methods were standardized for road improvement works (Manual of Pavement Investigation and Testing Methods of Japan Road Association, etc.).

Tests used for porous concrete other than pavement include ultrasonic propagation velocity measurement for detecting internal deterioration and infrared thermal image processing for measuring the percentage of vegetation cover. However, most of the methods have not been standardized.

Moreover, no direct in-situ testing methods have been established for measuring pore properties and strength, which are the most important indices. At present, tests are commonly performed by using a specimen of the same mix proportion or a core sample drilled at the site. However, a specimen has been reported to receive wall effects, and a core sample is susceptible to internal damage caused by drilling [3]. To solve these issues, nondestructive and micro-destructive tests are being investigated.

Photo-1 Example of in-situ water permeability test

5.3 Indoor testing methods

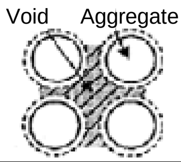
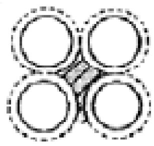
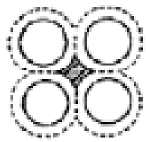
Indoor testing methods have been relatively well standardized. The committee modified existing testing standards so as to reflect recent study results.

Compressive and bending strength tests are prescribed to follow the testing methods for ordinary concrete stated in JIS A1108 and 1106, respectively. In the committee report, the effects [4] of the ratio (h/d) between the height and diameter of the specimen on the results of compressive strength test are explained.

For JCI-SP02-1 “Method of testing void content of porous concrete (draft)”, the definition of voids was modified as shown in **Table-3**. A testing method of the volume-pressure method that uses a concrete air meter was added.

For JCI-SPO3-1 “Method of testing water permeability of porous concrete (draft)”, it was pointed out anew that the resultant coefficient of permeability fluctuates by changes in hydraulic gradient during measurement [5]. Therefore, the phenomenon was stated, and hydraulic gradient was added in the items to be reported.

Table-3 Classification and names of voids

<table>
<tr><td colspan="2">Schematic view of void</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Drainage</td><td>Easy</td><td>Requires time</td><td>Difficult</td></tr>
<tr><td colspan="2" rowspan="2">Name of void</td><td>Continuous void</td><td>Semi-continuous void</td><td>Independent void</td></tr>
<tr><td colspan="3">Entire void</td></tr>
<tr><td colspan="2">Major properties affected</td><td colspan="3">←Water permeability→ ←Pumping and water retentiveness→
← Strength and mechanical properties →</td></tr>
<tr><td rowspan="3">Names of voids in the 2003 report</td><td rowspan="2">Volumetric method</td><td>Continuous void</td><td>Independent void</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Entire void</td></tr>
<tr><td>Weighing method</td><td colspan="3">Entire void</td></tr>
</table>

5.4 Durability test methods

5.4.1 Freeze-thaw resistance

In this report, two new testing methods are proposed, which differ in method of immersion, based on recent study results. The two methods mutually differ in test conditions. It is assumed that the user considers the actual environment at the place where the concrete is used and selects the method appropriate to the conditions. Henceforth, it is necessary to accumulate data on these tests and clarify the relationship with porous concrete in actual service environment.

5.4.2 Resistance to repeated drying and wetting

A method (draft) was proposed for testing the resistance to repeated drying and wetting in the report (2003) of the previous committee. Later, Public Works Research Institute proposed a method of improved practicability [6]. In this report, the latter method was decided to be adopted.

5.4.3 Leaching resistance

On leaching resistance, a common experiment was conducted by the former committee (2003), and an indoor test method was proposed [7]. However, the method requires a long time for measuring, and the relationship with calcium leaching in actual environment is not clear. Therefore, the committee judged that further investigation is needed, and decided not to propose a testing method in this report.

5.4.4 Abrasion resistance

Methods for testing abrasion resistance other than Cantabro test, which is standardized by ZKT (Japanese ready-mixed concrete association), require specific machines and are difficult to perform. Therefore, the committee decided not to propose a testing method in this report.

5.4.5 Skid resistance

Skid resistance is tested by using methods standardized in the field of pavement. However, like in ordinary pavement, there have been no clear standards shown and the relationships among various measurement methods are not clear. Therefore, a method appropriate to the service conditions needs to be selected, and appropriate standard values need to be set.

5.5 Quality evaluation test methods for fresh concrete

Several tests have been standardized for evaluating the compaction and sagging. The methods have already been used in practice by setting control values for each condition of construction. It is expected that further objective and quantitative quality control would be performed at more sites.

6. Joint experiments and a draft of strength control method

The committee conducted joint experiments to prepare a draft of strength control method. At present the strength of porous concrete is controlled, as in ordinary concrete, most commonly by preparing a control specimen separately from the constructed structure. However, the properties of porous concrete are easy to change by construction method, and thus the separately prepared specimen is possible not to be reproducing the properties of the porous concrete in the structure appropriately. Therefore, porous concrete needs an original strength control method.

The common experiments were conducted to present methods for estimating compressive and bending strengths from the actually measured void content of structural porous concrete. In principle, the strengths are estimated according to the following procedure:

a) Measuring the void content of a specimen excised from structural porous concrete and
b) Estimating the strength from the measured void content by using the relationship between strength and void content.

In the common experiments, eight institutes cooperated. The relationships between strengths and void content can be approximated by the following exponential functions in general. Here, the functions were normalized into a form independent from the strength of the binder.

$$y = A \exp(-Bx)$$
$$y' = \exp(-Bx)$$

where y: strength (N/mm^2), x; void content (%),
A: strength of the binder (N/mm^2), B: empirical constant and
y': strength ratio = y/A.

From the results of the common experiments, the following knowledge was acquired.

1) The method of sampling the specimen had little or no effect on the relationship between strength and void content. In other words, compressive strength did not differ between a cylindrical specimen (control specimen) and core specimen; and bending strength did not differ between a square pillar specimen (control specimen) and excised specimen as well.
2) As shown in **Figs.-4 and 5**, the relationships between strength ratios and void content can be approximated by the following equations.

$$Fc' = \exp(-0.08x)$$
$$Fb' = \exp(-0.07x)$$

where Fc': compressive strength ratio, x: void content (%) and
Fb': bending strength ratio.

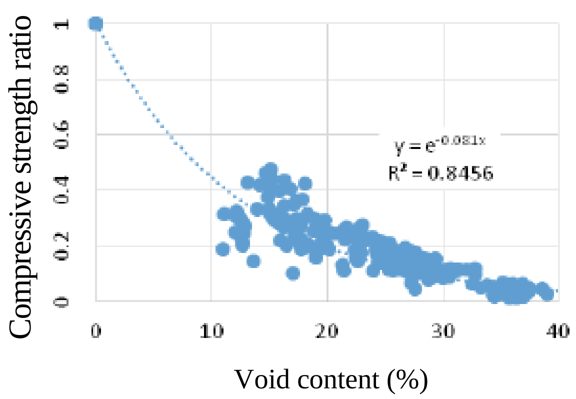


Fig.-4 Relationship between compressive strength ratio and void content (cylindrical and core specimen)

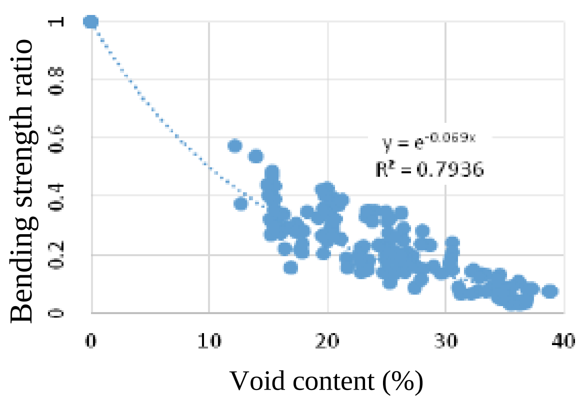


Fig.-5 Relationship between bending strength ratio and void content (square pillar and excised specimen)

As a whole, the common experiments resulted in dispersed strength ratio values even for a single void content. However, the correlation of the experimental data in each institute was very high (data not shown). Therefore in the strength control method (draft) (See **Table-4**), it was decided that each institute was to prepare its own relationship between strength ratio and void content in advance and use the relationship to control strength (2) and 3) in Table-4).

Table-4 Strength control method (draft)

The strength of porous concrete is to be controlled by either of the following methods:

1) Testing a specimen sampled from the structure
2) Estimating from actual void content measurement of the structure and the relationship between strength and void content prepared by the institute
3) Estimating from the void content estimated from the target void content and degree of compaction and the relationship between strength and void content prepared by the institute
4) Using an original method of the institute

7. Design guidelines for porous concrete (draft)

7.1 Introduction

Design guidelines (draft) that involve checking performances were prepared for pavement and greening revetment, which are two fields where the advantages of porous concrete can be manifested.

7.2 Design guideline (draft) for pavement

The table of contents of the design guideline (draft) for porous concrete pavement is shown in **Table-5**.

Table-5 Design guideline (draft) for pavement

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Chapter 1 General

1.1 Scope 1.2 Basics of design 1.3 Definition of terms

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Chapter 3 Method of checking performances

Chapter 4 Designing structure

4.1 Setting cross section of pavement 4.2 Design values of materials

4.3 Actions (loads)

Chapter 5 Checking performances

5.1 Checking safety 5.2 Checking serviceability 5.3 Checking durability

5.4 Checking the drainage properties of road surface

Chapter 6 Structural detail

Chapter 7 Maintenance

At the stage of designing, it is necessary to thoroughly investigate the performances required to porous concrete pavement, set appropriate performance levels, and decide the shape, dimensions, materials, mix proportion and maintenance method of the porous concrete pavement so that the required performances are fully satisfied. Advantages of porous concrete pavement can be manifested by using the concept of life cycle cost in making decisions. In general, porous concrete has superior mechanical properties compared to drainage pavement, which uses asphalt binder, but requires measures against reduced permeability caused by clogging of voids. Therefore, porous concrete requires an appropriate maintenance plan to be formulated and should be designed by also considering future maintenance works. As described above, clogging and resultant deterioration in performance, as well as possible remedy measures, need to be predicted when designing the pavement. It should be especially noted that focusing too much on strength may result in small void content and thus early loss in water permeability.

Required performances were decided to include safety, serviceability, durability and the drainage properties of road surface in general. To facilitate combining required performance levels, a simple combination guide was prepared between highway class and required performance levels (**Table-6**). The performances of porous concrete pavement were decided to be checked by using the indices shown in **Table-7**. Appropriate indices are needed to check that the performances satisfy the required levels.

Table-6 Examples of combinations of purpose and required performance levels

		Safety (trafficability)	Serviceability	Durability	Drainage properties of road surface
Class 1	Expressways, national highways (heavy traffic), toll gates, etc.	◎	◎	◎	△
Class 2	National highways, regional highways (ordinary traffic), etc.	○	○	○	○
Class 3	Roads in residential areas, parking lots, etc.	△	△	△	◎

Table-7 Examples of indices used for checking performances

Safety:	(bending) strength, fatigue resistance (wheel load, temperature load)
Serviceability:	skid resistance, sound absorbency, aggregate scattering resistance, crack resistance, light color, flatness, lower road surface temperature, vibration reduction
Durability:	abrasion resistance, freeze-thaw resistance, thermal stress resistance Drainage properties of road surface: void content, coefficient of permeability

Porous concrete pavement should be maintained by formulating an appropriate maintenance plan because porous concrete is susceptible to performance deterioration while in service due to clogging, etc. but is possible to be restored by cleaning, etc. Inspection frequencies can be determined by referring to ordinary structures and existing pavement; but works to be performed to maintain porous concrete, such as removing clogs, need to be decided by fully considering the ambient conditions of the pavement and referring to knowledge acquired in the past. Inspection can be ordinary visual inspection, but the drainage properties of road surface are desirably examined when it is raining.

7.3 Design guideline (draft) for greening revetment

One of most widely used existing design and construction guidelines is “Guideline on methods of construction for river revetment using porous concrete (Ed. Advanced

Construction Technology Center, 2001)". Because it has already passed 14 years after the publishment as of today, the committee aimed at preparing a design guideline that involves checking performances by revising the content of the guideline when necessary. The table of contents of the so prepared design guideline (draft) for greening revetment by using porous concrete is shown in **Table-8**. River revetment that uses porous concrete should be designed after conducting thorough preliminary survey of the site to understand the environmental conditions to which the revetment is to be exposed in detail. The results are then to be organized; and the kind of revetment, structural specifications and the constitution of the revetment are to be decided.

Table-8 Design guideline (draft) for greening revetment

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1.1 Scope 1.2 Basics of design 1.3 Definition of terms
Chapter 2 Setting required performances
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Chapter 4 Designing structure
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Chapter 5 Checking performances
5.1 Checking safety 5.2 Checking durability 5.3 Checking vegetation
Chapter 6 Maintenance

There are three kinds of river revetment: 1) low water revetment for stabilizing the flow of low water channel, where the river water flows, and protecting flood channel from scouring, 2) high water revetment for protecting levee during flood, and 3) levee revetment for directly protecting the entire levee including low water channel and up to the high water level. Low water revetment and levee revetment are frequently submerged under water and prone to soil erosion and sedimentation depending on flow regime. On the other hand, high water revetment is rarely flooded, and the moisture condition is severe for plants. Floodplain protection is installed to prevent scouring near the ground sill, which is caused by turbulence on floodplain. River revetment that uses porous concrete is required to possess the performances required to ordinary concrete river revetment plus a specific performance of allowing vegetation growth. The performances required to river revetment that uses porous concrete vary depending on the purpose and ambient conditions, and thus must be properly decided.

Safety is the resistance against displacement of the structure under assumed stream effect and the resistance against destruction by colliding driftwood. Durability is the resistance of the structure against time-historical performance deterioration caused by deterioration of the materials of the structure under the assumed actions. Vegetation is the performance of allowing plant species, which are selected based on the continuity with the peripheral natural environment and safety, to grow to a target level within the target period of time and sustainably maintaining the species. For example, the performances required to river revetment that use porous concrete can be classified as shown in **Table-9** by the river environment and point of focus. The set required performances were decided to be checked by using the indices shown in **Table-10**.

Table-9 Classes of general river revetment consisting of porous concrete

Class	Point of focus	River area	Safety	Durability	Vegetation	Notes
Class 1	Vegetation	Middle basin - brackish water	◎	△	◎	This is applied for sections that especially focus on vegetation or areas of severe climatic conditions for plants.
Class 2	Both vegetation and safety	Upstream area - brackish water	◎	○	○	—
Class 3	Safety	Upstream area - middle basin	◎	◎	△	—

Table-10 Examples of indices used for checking performances

Safety:	slide resistance, impact resistance
Durability:	erosion resistance, abrasion resistance, freeze-thaw resistance, resistance against chemical attach, resistance against biological attack, resistance against alkali-silica reaction
Vegetation:	thickness of cover soil, revetment correction, void content, minimum diameter of coarse aggregate

8. Porous concrete manufacture and construction guidelines (draft)

8.1 General

As described above, more than 10 years have passed since the former committee published its report. Latest information on porous concrete was thus collected by also conducting experiments. Based on the result, the manufacture and construction guidelines (draft) (hereinafter referred to as the "guidelines (draft)") was summarized.

Properties required to porous concrete vary depending on the target structure. Therefore, extents that can be generalized in the manufacturing methods were generalized in the guidelines (draft); and points to note are stated for each of other structures. Columns describing knowhow on manufacture and construction of porous concrete were inserted in the guidelines (draft) to provide reference information to readers.

8.2 Methods of manufacture

(1) Materials

Materials used for porous concrete are stated based on actual uses. Differences from ordinary concrete in terms of material include exemplification of methods of lowering pH, recommended use of aggregates of uniform size, and use of aggregates that contain less fine particles than JIS A 5005 standard value.

(2) Mix proportion

The mix proportion of porous concrete should be determined by considering the balance between void content and strength. On the void content required to porous concrete, the guidelines (draft) shows the relationship between total void content and continuous void content. It should be noted that the design strength differ depending on structure.

Unlike in ordinary (reinforced) concrete, the durability of porous concrete is not related to corrosion of internal steel but should be considered from the viewpoint of tissue destruction. In other words, the durability of porous concrete includes freeze-thaw resistance, resistance against repeated drying and wetting, abrasion resistance and accompanying skid resistance and aggregate scattering resistance.

Consistency is required so as to compact the concrete to have the required void content. Attention is needed on separate sedimentation of cement paste.

The method of designing the mix proportion of porous concrete differs from that of ordinary concrete. For porous concrete, the unit weight of coarse aggregate is determined first based on the solid content. Then the amount of mortar or cement paste is determined based on the required void content. From the viewpoint of preventing separate sedimentation of cement paste, it is a widely used practice to include fine aggregates.

(3) Mixing and transportation

Porous concrete has particularly low water content. Therefore, the manufacture requires frequent monitoring of the percentages of surface moisture on both fine and coarse aggregates and reflecting the results in the batch. It should also be noted that the amount of surface water on coarse aggregates, which are used in a large quantity, also has a big impact.

Care should be taken while transporting porous concrete because the effects of drying on consistency become prominent. For using an agitator vehicle, it should also be noted that porous concrete is susceptible to blockage upon loading.

8.3 Cast-in-place porous concrete

(1) River revetment, etc.

Cast-in-place construction of river revetment or revetment for pond by using porous concrete is prone to inferior workability and/or reduced strength by drying because the void size is larger than in other structures. Therefore, measures to minimize the effects of drying are needed during transportation and during and after placement. As shown in **Photo-2**, a measure is also needed for placing porous concrete over a relatively steep slope. Many of such constructed revetments are covered by soil and/or water retentive materials, which serve as filtering and filling materials, for greening. The guidelines (draft) states matters that require attention concerning checking the quality of porous concrete and work processes in detail.

Photo-2 Compaction of revetment by a backhoe

Photo-3 Spreading by an asphalt finisher

Photo-4 Slope protection by spraying (semi-dry)

(2) Pavement of pedestrian way and parking lot

Porous concrete pavement of relatively low load is used for pedestrian ways and parking lots. The pavement is prone to clogging relatively early due to soil inflow, etc. although the susceptibility depends on the ambient conditions. Therefore, it is advised to implement a countermeasure(s) against soil inflow, etc. as a pavement structure at the design stage. Because it is paving, contraction and expansion joints need to be constructed. Examples of joint structures of various kinds are shown in the guidelines (draft).

(3) Pavement of roadway

For using porous concrete to pave roadway, a construction method of a pavement structure that can bear live load is described, which involves laying a functional layer of porous concrete over ordinary cement concrete pavement. Because fresh porous concrete is placed on hardened concrete slab, foul layer is commonly installed. Joints are naturally installed on roadway pavement; but dowel bars for transmitting load are installed within the slab that constitutes binder course and not in the upper slab of porous concrete. Regarding materials and mix proportion, skid resistance and abrasion resistance need to be considered as well as ordinary performances. Spreading and compacting are similar to those for extremely stiff consistency concrete, but are to be executed not by using a vibratory roller or tire roller but by using a high compaction screed or an asphalt finisher with reinforced screed as shown in **Photo-3** in order to keep voids.

(4) Slope protection

Spraying porous concrete over slope is executed as a cast-in-place method for protecting slope, which is steeper than river revetment, etc. Reinforcement during construction for keeping porous concrete on steep slope may either involve installation of honeycomb mesh formwork (**Photo-4**) or installation of steel netting or wire netting and mixing short organic fibers in the concrete. There are two spray methods for each reinforcing method: the semi-dry method that adds mixing water several times, and the wet method. The methods differ in mix proportion.

(5) Water purification

Use of porous concrete for water purification aims to reinforce and complement the natural functions of river of capturing and decomposing pollutants and to mitigate the pollution of the river by providing appropriate maintenance. Phosphorus removing function can also be added by also growing plants (flora).

To maintain the water purification function of porous concrete, it is crucial to keep the biofilm that inhabits the surface of the porous concrete. Therefore, the concrete needs periodical cleaning and/or renovation. When plants are grown, periodical mowing, etc. is also needed.

8.4 Industrial products

Industrial products that use porous concrete are classified into porous concrete blocks for pavement, river revetment blocks for vegetation and ordinary porous concrete products such as those for collecting underground water and infiltrating rainwater into the ground. Among them, there are products consisting of both ordinary and porous concrete.

Unlike other target products, tension members are not installed in porous concrete although there are cases in which precaution reinforcement is arranged.

Basically, materials and mix proportion are similar to other target products. Blocks are manufactured by instant stripping, and products other than blocks are manufactured via the same procedures used for ordinary precast concrete products. Caution to be exercised during manufacture is on sharp changes in consistency by drying, and thus the leaving time (the period of leaving the mixed concrete until placement) should be set short compared to ordinary concrete.

9. Closing remarks

The study committee on establishment of construction standards and quality assurance system for performance-based design of porous concrete has acted and presented performance-based design guidelines (draft) and manufacture and construction guidelines (draft) of porous concrete. It is desired that they would serve as a basis for preparing future practical design guidelines etc. in Japan. It would be an unexpected joy if they lead to proper evaluation of diverse and attractive performances of porous concrete and sound development as materials for social infrastructures.

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