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ORGANISM ADAPTABLE CONCRETE

Motoharu Tamai [1]
Hiroyuki Mizuguchi [2]
Takahisa Okamoto [3]

Abstract

The purpose of this study is to search for ecologically acceptable ways to stimulate the natural self-purification activities in civil engineering construction fields. Porous concrete, through which water and/or air can pass freely, is assumed to be the organism adaptable concrete, as planting and water purifying concrete. This paper discusses the properties of porous concrete and its applications to the environment. As a result, porous concrete is thought to be useful in the establishment of a well-balanced biological environment.

KEYWORDS: *biological environment, continuous voids, ecological concrete, organism adaptable concrete, planting, porous concrete, water purification*

1. Introduction

This paper describes the concept of eco-concrete, to which living organisms can adapt, and the physical properties of porous concrete with continuous voids. It shows that this concrete can be used for planting and water purification. Although conventional concrete has been regarded as a destroyer of nature, water and air can pass freely through concrete when it is made porous by forming continuous voids (Tamai, 1988). This not only enables plants to vegetate, but also makes it possible for microscopic animals and plants, including bacteria, to attach to and inhabit uneven surfaces as well as internal voids when the concrete is provided in a natural water area or waterside area (Tamai, 1992). A positive biological environment is created which provides a habitat for various organisms (JCI, 1995a). The utilization of this type of concrete, therefore, aids in the preservation of our global environment as well as creates a regional environment. The contents of the report have been summarized in a committee report on ecological concrete by the Japan Concrete Institute (JCI, 1995b).

1) Concept and philosophy (Hiroyuki Mizuguchi, Takashi Sakai, Kenji Kawai and Noriyoshi Arimori)
2) Usage and requirement of ecological concrete (Katsunori Demura, Fumio Kaneko, Takaaki Okubo, Kazuo Oyabayashi, Yukihiro Shimatani, Hiroshi Tabuchi and Tutomu Fukute)
3) Investigation of the application of porous concrete (Takahisa Okamoto, Noboru Yasuda, Kazuo Amo, Fuminori Sato, Hiroyasu Shimada, Yasuhiko Furusawa, Naoki Masui, Kyuichi Maruyama and Kunio Yanahashi)

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1 D. Eng., Professor, Dept. of Civil Eng., Kinki University, Kowakae, Higashi-Osaka, 577, Japan.
2 D. Eng., Professor, Dept. of Civil Eng., Tokushima University, Minami-Josanjima-cho, Tokushima, 770, Japan.
3 D. Eng., Chief Engineer, Center Institute, Nihon Cement, Co, Ltd. Kiyosu, Koto-ku, Tokyo, 135, Japan.

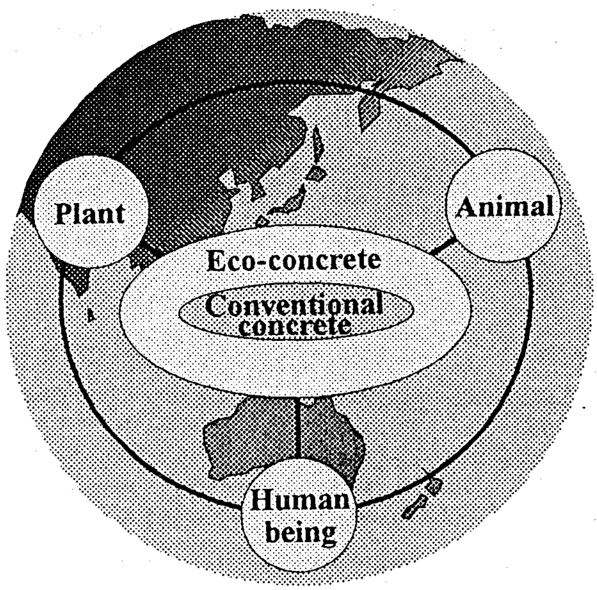

Figure 1. Concept of ecological concrete

2. Concept of Organism-Adaptable Eco-concrete

Organism-adaptable eco-concrete is capable of striving toward harmony, or symbiosis, within ecosystems. It is devised to secure habitats for organisms or to at least not adversely affect the organisms. For this type of concrete, ingenuity has been exerted on the structural level, such as relates to the mode of the structure and its location, and on the material level, such as concerns the component materials. Specifically, concrete which provides a large quantity of attachment surfaces or spaces for aquatic life to secure habitats, or has continuous voids in which the root systems of herb plants can enter for growth and immobilization, corresponds to this type. In addition, concrete which does not adversely affect the inhabitation of living organisms, the structural modes which reduce the elution of the alkali content, or assist the organisms with inhabitation by making the internal transport of moisture or gas run smoothly, also correspond. These concepts are schematically shown in Figure 1 (Sakai, 1996).

3. Physical Properties of Porous Concrete

Porous concrete, suitable for an inhabitable environment for organisms, is positioned in the design stage to belong to a composite area for bedrock, structural concrete, gravel ground, etc. (Tamai, 1992). When it is expressed in two dimensions, strength and permeability, the concept of each material can be shown as in Figure 2 (JCI, 1995b). Using these materials, it is necessary to determine the design items which specify a performance in accordance with the required use and functions. The basic mode of utilization, the percentage voids, permeability and strength, which are typical test items that fulfill the design requirements, are shown here. Generally speaking, these items are tested in order to evaluate their performance. Concrete

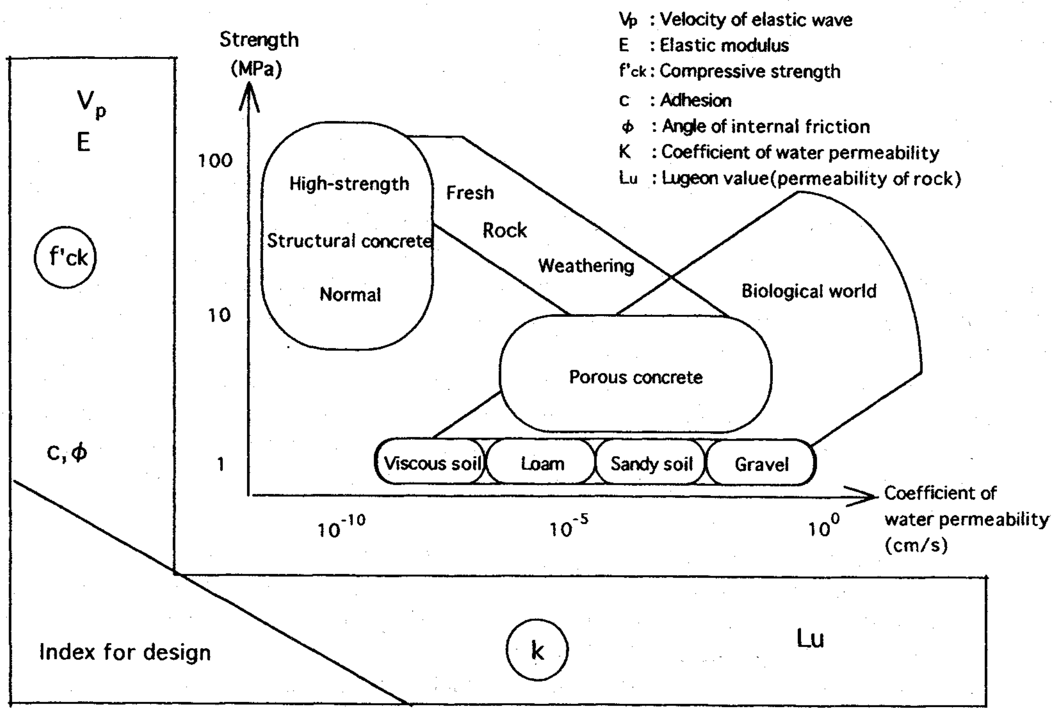

Figure 2. Concept of the properties of porous concrete

for water purification must undergo tests on the permeability coefficient, the total percentage voids, and the continuous percentage voids. Concrete for planting must undergo tests for void diameters, continuous percentage voids, pH, etc. (Yanagishi, 1996; JCI, 1995b).

3.1 Total percentage voids and continuous percentage voids

Voids in porous concrete are independent and continuous. For organism-adaptable co-concrete, continuous percentage voids are important elements. Concrete used for planting, organism inhabitation or water purification ought to have as many large percentage voids and as large void diameters as possible. However, there are limits due to their correlation to strength. Practical values for the continuous percentage voids and the void diameters are thought to be 20 to 30% and 1 to 5 mm, respectively (Matsukawa, 1996).

3.2 Permeability

The permeability of porous concrete depends upon the aggregate grain diameter, the size of the void diameters, and the continuous percentage voids, and is greatly affected by the difference in heads. Therefore, great care should be taken. The value of the permeability coefficient (K) is preferably 2 cm/s or more, assuming that the difference in heads is 5 cm for planting concrete, considering the entry of root systems (JCI, 1995b). Concrete for organism inhabitation or water purification should have a (K) value of 1.5 cm/s or more, assuming that the difference in heads is 5 cm. This is because a supply of water containing oxygen is necessary for creating inhabitable spaces for bacteria and small animals that they will continuously inhabit (JCI, 1995b; Mizuguchi, 1996).

3.3 Compressive strength

In order to prevent damage during manufacturing, transportation, and installation processes, an adequate amount of strength is necessary. And to continuously withstand use, durability is also vital. The strength of porous concrete differs depending upon the place at which it is used and the purpose and method of its utilization (Malhotra, 1976; Tamai, 1989). Generally, however, about 15 to 20 N/mm^2 are necessary for planting concrete, and a strength of about 20 N/mm^2 or more is desirable for concrete used for water purification or for the inhabitation of organisms (JCI, 1995a).

Five laboratories conducted evaluation tests on total percentage voids, continuous percentage voids, the permeability coefficient, and the compressive strength of specimens manufactured by their own methods in accordance with the physical property testing method of the Committee on the Ecological Concrete of the Japan Concrete Institute. The following conclusions were obtained:

1) The permeability coefficient is based on Darcy's Law, but it should be displayed together with the value of the hydraulic gradient because it may be affected by the difference in heads (hydraulic gradient) depending upon the properties of the voids or the values of the continuous percentage voids (JCI, 1996b).
2) When it is displayed by the permeability coefficient at the head difference corresponding to a hydraulic gradient of 0.2 to 0.3, there are no problems with its practical use (JCI, 1996b).
3) The compressive strength seems to be proportional to the quantity per unit volume and strength of the binder, and inversely proportional to the aggregate grain diameter (Tamai, 1989; JCI, 1996b).
4) By conducting tests in accordance with the "Physical Property Testing Method (Draft)", proposed by the Committee on the Ecological Concrete of the Japan Concrete Institute, the physical properties can be substantially grasped (JCI, 1996b).

4. Mode of Utilization and Performance Requirements

4.1 Mode of utilization

The eco-concrete must have the required amount of strength and durability, like ordinary concrete, and fulfill special functions as an eco-material. In regards to, for example, the strength and durability properties, there is also a method for compounding ordinary concrete and a method for improving concrete by mixing in a fibrous material. Depending upon the respective modes of utilization, such as the vegetation of plants, water purification, and environmental preservation, however, the void diameter, the total percentage voids, the continuous percentage voids, the permeability, etc., of the physical properties, and the presence or absence of the elution of free lime as a chemical property change due to differences in internal factors. Therefore, it is necessary to provide eco-concrete that is suitable for each designated purpose.

Table 1. An example of the flow of the material plan for the performance requirements

●Items	
Use/Purpose	Planting, water purifying, creating a habitant for organisms, Recovery/ restoration/ regeneration of the natural environment, view, etc...
Performance place	Planting/ recovery of the natural environment: riverside, slope of the ground / building lots Water purifying/ recovery of the natural environment: rivers/ lakes/ marshes / seasides
Application method	Plants : lawn, weeds, shrubs, algae, etc... Animals : bacteria, protozoa, crustacea, shellfish, etc...
Practical form	Sole material of the porous concrete, composite with normal concrete, cooperation with polymer emulsion or fiber materials, porous concrete with reinforced materials
Durable years	2 to 3 years: base protected by shrubs on the slope of the ground 10 to 20 years: in the case of recovery/ restoration of the natural environment in a short period 20 to 30 years: regulation of the reef in 30 years 30 to 50 years: regulation of the steel materials used in the marine area in 50 years
Material	Selection of the materials and mix proportions of porous concrete depend on the desired value of the material properties.
●Needed item	These properties are strength, void ratio, void size, water permeability, elusion of free lime, etc...
Strength · · · · ·	Strength: depends not only on the aggregate size but also on the strength of the binder and its quantity.
Voids ratio · · · ·	Void ratio and void size: depend on the kind of aggregate (size and void ratio) and the quantity of binder.
Durability · · · · ·	Durability: freezing and thawing resistance of the material compard with normal concrete is weak in the water, and a little weak in the air.
●Effective item Other ability	*Decide on the essential properties of the eco-material* and expect the basic factors of strength, void ratio, durability, etc... Water permeability: kind of aggregate (size of particle, void ratio, grading, etc...), quantity of binder and the test method (water head and temperature of water) Free lime elution: Free lime to be eluted intensively from porous concrete, because the internal surface asea of this concrete is rough and very large. Such water sometimes has a negative influence on animals and plants, especially when they are young.
Quality control	Internal structure/ Void formation Distribution of micro-pores, independent and continuous voids, water absorption, water/ humidity/air permeability, specific heat and sound isolation Surface characterization Thermal conductibity, coeffcient of sound absorption, surface hardness, friction resistivity. Strength compresive/ flexural/ tensile/ shear strength, dynamic/ static modulus of elasticity. Durability carbonation, durability factor, drying-shrinkage coefficient, pH.
Control of practice /maintenance	Control of the practice and maintenance are carried out by suitable methods for practical field situations.

4.2 Control of physical properties to satisfy performance requirements

With standard percentage voids for porous concrete of 20 to 30%, many factors are required such as the characteristics of binder, size, shape, quantity, etc. of the independent voids and the continuous voids. An example of the flow of the material plan for these performance requirements is shown in Table 1 (JCI, 1995b).

4.3 Request items from chemical materials

The materials which constitute concrete are almost all inorganic materials, except for the chemical admixture. And inorganic injurious materials eluting from a hardened object, provided in the Water Pollution Prevention Act, are below the order of ppb or not detected at all.

As regards the chemical admixture, the amount of injurious material and the upper limit of LD50 against a mouse and rat have been prescribed by the JSCE, and it is considered to be safe for living organisms. However, the elution of free lime from porous concrete is great at the beginning stages in water areas and leads to lowered strength, and therefore, care should be taken. When concrete is set in water or in waterside areas, organisms around it may at first be adversely affected. Therefore, countermeasures such as neutralizing the surfaces before use or mixing in an admixture material which reacts with free lime, such as pozzolan or polymer emulsion, are desirable.

5. Adaptation of Porous Concrete

5.1 Application to land environment

For land organisms to inhabit the surfaces or the interior of concrete, it is necessary to make the concrete porous, and yet, the concrete must not adversely affect the inhabitation of microscopic organisms, small animals, plants, or vegetating organisms (Yoshimori, 1996; Horiguchi, 1995). Photograph 1 shows the surface of porous concrete with continuous voids.

1) Concrete in which plants grow: It is necessary to artificially create the functions which soil has. It is also essential to prevent any alkali content or salts from eluting, and to give space in which root systems can extend, the ability to hold fertilizer, the ability to hold water, and permeability. An example of concrete for planting, for which implementation works have been conducted, is shown in Photos 2 and 3.
2) Concrete which allows for the inhabitation of microscopic organisms and small animals. In order for microscopic organisms in soil, such as bacteria and mold fungi, and small animals in soil, such as eelworms, insects, spiders, earth worms, and springtails to inhabit concrete, adequate voids, water holding ability, permeability, and organic material such as humus, which becomes bait, are required.

5.2 Application to water area environments

(1) Rivers and lake environments and eco-concrete

Rivers and lakes are composed of water, shores, bottoms, structures, and so on. These spaces and the water in them are made integral to from habitats in which organisms habitate.

These habitats are where each organism goes through their life cycle, and it is necessary to ensure continuity between habitats which is required for their life cycle.

Porous concrete forms continuous voids and is characterized by air permeability, water permeability, the retention of moisture, the texture of its surfaces, etc.. If it is provided in the water or in waterside areas, algae will attach to it and habitats for small animals such as protozoa are formed. Thus, positive environments are also thought to be created for insects and fishes.

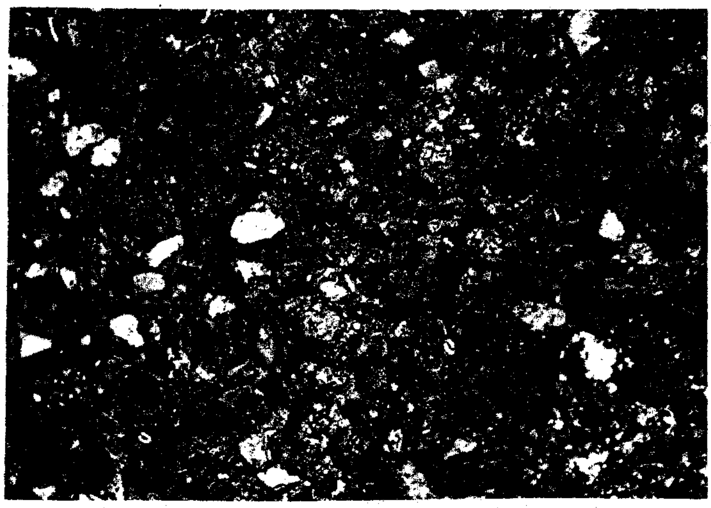

Photo 1. Surface of porous concrete

Photo 2. Example of planting concrete

(2) Ocean environment and eco-concrete

In considering the use of eco-concrete in the ocean, there is a method of studying the ecological characteristics of concrete in view of the material aspect as "eco-concrete material" such as porous concrete, and there is a method of studying it in view of "eco-concrete space" as an ecological space which is created by concrete materials and concrete structures. Concrete has a wide scale of space size such as fine space, void space like porous concrete, and macro space created by concrete structures in the characteristics of the material. On the other hand, the ecological scale also has multiple hierarchical structures, from micro to macro, and includes

Photo 3. Field work of planting concrete

Photo 4. Attachment of organisms to the porous concrete in water area

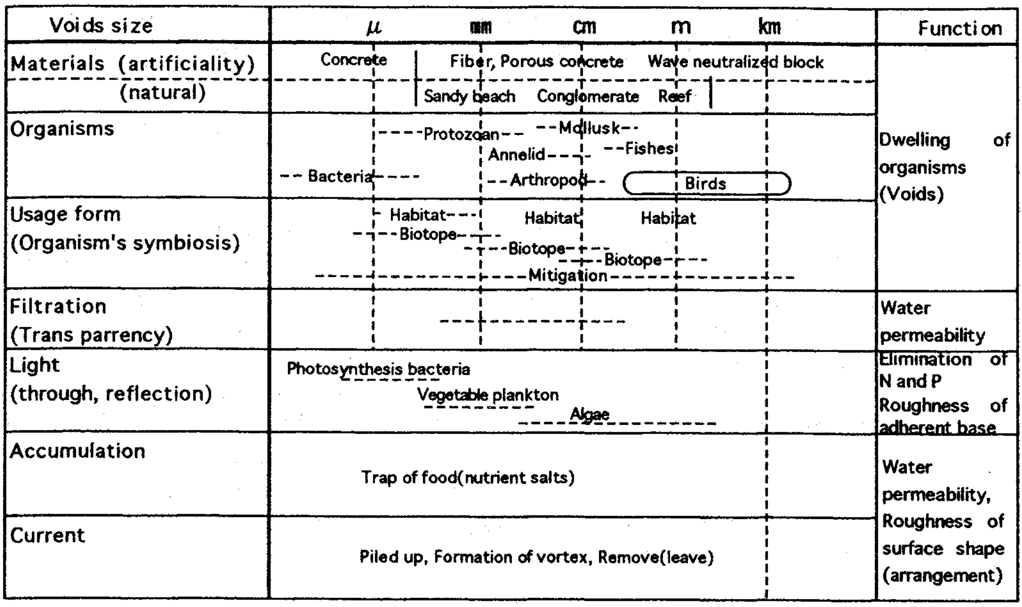

Figure 3. Relationship between void properties and organisms in habitats and items relating to water purification (JCI, 1995b)

an exceedingly wide scale from distance scale to time scale.

Continuous void diameters of porous concrete vary according to the aggregate used and the amount of binder, but their general values are from 0.01 to 10 mm (JCI, 1995b; Matsukawa, 1996). For organisms which inhabit such spaces, bacteria, protozoa, small animals and the like are considered. Since the surfaces are uneven and have air permeability and water permeability, however, various adherent organisms seem to inhabit them (Photo 4.).

(3) Water purification

The water purification function of porous concrete is based on the operation of a biological membrane formed on the surfaces of the concrete. Various organisms, from bacteria to large-sized animals, including unicellular algae, small animals, large-sized algae, and shellfish, inhabit the biological membrane in accordance with the environmental conditions. And thus, a type of ecosystem is thought to be formed on the biological membrane. As a method of purifying the water using the biological membrane, there is an inter-gravel catalytic oxidation method which uses a natural stone or concrete lump with a diameter of 20 to 30 cm. Since the porous concrete has internal voids, it is thought that microscopic organisms easily inhabit this concrete, the biological membrane is formed complicatedly, and the ecosystem is diversified depending upon the void properties. If revetment and the like in coastal areas or rivers are constructed with porous concrete, the water purifying ability of nature is predicted to be further improved than ever before.

The principle of water purification, using microscopic organisms, lies in the biotic immobilization and metabolic degradation of pollutants. The purification ability of porous concrete depends upon the quantity and the kind of inhabiting microscopic organisms, and the surrounding environmental conditions such as incubation conditions for activating the metabolic function of the microscopic organisms. Figure 3 shows the relation between void properties, characterized by porous concrete, and the inhabitants and other items related to water purification.

6. Conclusion

Concrete has been studied in order to provide it with minuteness and an improved performance, such as higher strength and higher durability, with the aim of utilizing it for structural materials. In light of the present status of our global environment, the authors *et al.* have researched eco-concrete, to which living organisms can adapt, in order to strive for human sustainable development and progress. In particular, the authors investigated the physical properties of porous concrete, which has a contact point with our biological environment, and its application to various environments. In the past, concrete has been regarded as a destroyer of nature. The results show, however, that by exerting ingenuity in various ways, such as making concrete porous or changing its surface properties, it is possible to use concrete for plants to vegetate or for small animals, including microscopic organisms, to inhabit. These findings suggest that concrete could be utilized as environment-creating material in land and water areas which would otherwise not have seemed suitable for such purposes in the past.

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