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Analysis of permeability and recovery rate for unclogging elastic surface filter and G-block for urban rainwater infrastructure regeneration

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Abstract

To economically solve problems for rainwater renovation, stormwater treatment at the early stage is needed for the storage and reuse of safe rainwater. One of the alternatives changes the conventional rainwater drain into an unclogging elastic surface filter (UESF). UESF manufactured with the ethylene propohlene diene monomer (EPDM) has a merit of not only primary treatment of stormwater but also rapid restoration of its permeability by hammering after surface pollutions. Accordingly, in this study, the durability of pavement materials is evaluated by measuring the permeability of UESF and prefabricated prototype called G-block after the removal of surface pollutants. Also, the relationship between coefficient of restitution and recovery rate is estimated. The permeability is measured again after the removal of surface pollutants to calculate the recovery rate. As a result, the permeability of UESF and G-block is much greater than the general permeability standard of 0.01 cm/s. After hammering, the permeability is recovered and the recovery rates of UESF and G-block are 22.22 and 55.6%, respectively. Therefore, it proved that UESF and G-block could improve the permeability and recovery rate for the field application and renovate the conventional rainwater drain for rainwater recycling at urban sites.

Key words: ASTM D 3574, coefficient of restitution, G-block, KS F 2394, permeability, recovery rate, unclogging elastic surface filter (UESF)

INTRODUCTION

Impervious concrete pavements installed in schools, parks, walkways, and bicycle roads have caused frequent local flooding in urban areas during wet seasons. Impervious pavements have also resulted in reduced ground water supply and increased dry streams due to lack of percolation (Kim *et al*. 2002).

Dramatic increase of the impervious surfaces due to rapid urban development produces an increasing number of nonpoint pollution sources. Especially, during precipitation, the pollution of urban runoffs to the local streams is one of the major environmental concerns (Son *et al*. 2009). Although increase in the number of treatment plants has eliminated some of the point pollution sources, improvement of the water quality still has limits due to many nonpoint pollution sources such as pollution of runoffs.

Korea experiences annual urban flooding due to high rainfall intensity during the wet seasons, and has made continuous effort to mitigate the flood damages and to improve the resiliency and redundancy of water supply/treatment infrastructures. Especially, elastic porous pavement is an eco-friendly resolution to frequent urban floods because it reduces surface runoffs and increases ground percolations. In fact, porous pavement techniques are gaining growing attention and applied in various urban areas. In addition, elastic porous pavement has been proven to enhance pedestrian comforts and driving safeties as well as to mitigate noise levels (Lee & Hwang 2007). However, elastic porous pavements are subject to rapid performance degradation caused by surface pollutions (Shin *et al*. 2009). Therefore, porous pavement capable of retrieving its initial permeability by simple tasks can be an attractive alternative to impervious pavement.

In this study, an elastic porous pavement prototype, called G-block, is developed by installing several porous and elastic materials in stacks and applied to a park to perform experiments on permeability and recovery rate. In the experiments, permeability, coefficient of restitution, and recovery rate of the prototype are measured, and its field applicability is analysed. To optimize the recovery process, the relationship between the coefficient of restitution and the recovery process is investigated after the recovery rates of permeability are measured.

MATERIALS AND METHODS

Permeability, coefficient of restitution, and the recovery rate of the unclogging elastic surface filter (UESF) and G-block installed at a park are measured and analysed.

Coefficient of restitution test

Coefficient of restitution of UESF and G-block is measured by freefalling a steel ball. The coefficient of restitution, one of the physical material properties, indicates the resilience of pavement material (Park 2010). In general, it is measured by calculating the percentage of restoring height after freefalling a steel ball from a certain height. The coefficient of restitution is calculated as followings: (Ball Rebound Test, unit: %)

$$\text{Coefficient of Restitution}(\%) = \frac{\text{Restoring height}}{\text{freefalling height}} \times 100\%$$

To measure the resiliency of the entire structure of UESF and G-block, Ball Rebound Test device is developed based on ASTM D 3574. In the experiment, a steel ball of 4.8 kg is used, and the freefalling height of 1 m is used. Then, the restoring height (m) itself can be the coefficient of restitution.

Figure 1 | Equipment for measuring coefficient of restitution and measuring coefficient of restitution.

Permeability test

Permeability of pavement can be represented by hydraulic conductivity attained by permeability test. As mentioned in the introduction, to improve permeability of pavement, UESF and G-block are implemented to satisfy the minimum standard hydraulic conductivity of 0.01 cm/s for general porous pavements.

Hydraulic conductivities of UESF and G-block are measured by 'Field Experiment Method for Porous Pavements (KS F 2394)'. The test device is presented in the Figure 2 below, and permeability value is calculated as followings:

$$K = \frac{L \times a}{A \times (t_2 - t_1)} \times \ln\left(\frac{h_1}{h_2}\right)$$

where $K =$ hydraulic conductivity (cm/s), $L =$ thickness of the pavement (cm), $A =$ cross section area of the infiltration (133.10 cm^2), $a =$ cross section area of the device (314.16 cm^2), $t_1 =$ starting time of measurement (s), $t_2 =$ end time of measurement (s), $h_1 =$ water level at t_1 (cm), and $h_2 =$ water level at t_2 (cm).

Figure 2 | Equipment for measuring permeability and measuring permeability of UESF.

Recovery rate test

Recovery rate of permeability is measured by comparing polluted and recovered pavement. The recovery procedure is done by hammering the pavement surface ten times with a constant force by the fabricated lab-scale hammering device. (*one blow by the hammering device generates an impulse of 0.104* $N \cdot$ s, *and the value is calculated by as followings*).

$$I = MH^2 + \frac{1}{3}mh^2$$

Figure 3 | Hammering device.

where $I =$ Impulse generated by one blow ($N \cdot s$), $M =$ head-mass of the hammer (0.78 kg), $m =$ rod-mass of the hammer (0.2 kg), and $h =$ total length of the hammer (0.35 m).

Then, the recovery rate of permeability is calculated as followings:

$$\text{Recovery Rate of Permeability } (\%) = \frac{\text{Permeability after Recovery}}{\text{Initial Permeability}} \times 100\%$$

UESF is installed in the fields and naturally exposed to surface pollutions for several years while G-block is artificially polluted by applying fine loess passed through 2 mm-sieve on the elastic porous pad surface. The reason that loess is used for surface pollution is based on the assumption that fine soil is the major source of surface clogging in the field applications. After numerous permeability tests on G-block specimen polluted with loess, approximately 30 g of loess applied on the infiltration surface ($A = 133.10\ \text{cm}^2$) reduces the permeability to 10% of its original one. The degree of pollution is quantified as g of loess per cm^2, which is equal to $0.225\ \text{g/cm}^2$ in this case.

Unclogging elastic surface filter

Prior to G-block fabrication, the structure and performance of UESF is evaluated. UESF is installed at five public parks in Daejeon, Korea. For each site, thickness of elastic layer, permeability, coefficient of restitution, and recovery rate of permeability are measured. UESF consists of a coarse aggregate layer, a support layer, and an elastic porous layer in subsequent order from the bottom. The cross-section view of UESF is described in Figure 4.

Figure 4 | Cross-section view of UESF.

G-block

Based on the structure of UESF and its field experiment data, G-block is similarly developed and fabricated. G-block consists of the conventional PE rainwater drain box, a steel grating, a HDPE support pad, PVC pad, and elastic porous pad made of ethylene propohlene diene monomer (EPDM) rubber chips and binder in subsequent order from the bottom. Detailed views including the cross-section are described in Figure 5.

Figure 5 | G-block and Layers of G-block.

Unlike UESF, G-block uses HDPE support pad instead of coarse aggregate layer because HDPE is lighter and easier for fabrication while providing comparable durability as coarse aggregate. Moreover, elastic flexural behaviour of HDPE pad significantly contributes to the total elasticity of the structure, increasing the coefficient of restitution and providing sufficient elasticity for pollutant removal.

Thickness of the elastic porous pad is designed as 1.5 cm based on the field experiment data that shows 1.5 cm gives the highest recovery rate. Four PVC pads, each of which is 0.7 cm thick are stacked right beneath the elastic porous pad. HDPE support pad and the steel grating are 5 and 3.2 cm, respectively. The total thickness of G-block layers is 11.5 cm, and the height of used rainwater drain box is 30 cm. The mix ratio of EPDM rubber chips to binder is 5:1, which is a bit higher than the general standard of 3.33:1, because 5:1 enhances the permeability without much deteriorating its structural durability.

RESULTS AND DISCUSSION

Field experiment data

Permeability of UESF in all five sites is measured as described in Table 2. General trend indicates that the permeability decreases exponentially as the age increases. Permeability after recovery varies from 0.007 to 0.152 cm/s, and recovery rate, 2.1 to 45.51%. Although permeability at W.K. park falls below the general standard of 0.01 cm/s after 8 years, the trend line projects that UESF will be still serviceable after 10 years. (*Permeability of 0.01 cm/s can handle 360 mm of hourly precipitation, a value far below the average maximum rainfall intensity of 145 mm in Korea.*)

Table 1 | Coefficient of Restitution and Thickness of Elastic Layer

	Freefall Height (cm)	Coefficient of Restitution (%)	Thickness of Porous Elastic Layer (cm)
S.K. Park	100	20.75	2.2
S.D. Park	100	7	1.5
S.J. Park	100	7.275	1.5
G.S.W. Park	100	16.625	2.3
W.K Park	100	13.75	2
Average	100	13.08	1.9

Thickness of porous elastic layer in USFEP varies from 1.5 to 2.3 cm, coefficient of restitution, from 7 to 20.75%. Most recently installed UESF shows the highest coefficient of restitution.

Table 2 | Result of Permeability and Recovery Rate

	Age (years)	Initial (cm/s)	Before recovery (cm/s)	After recovery (cm/s)	Recovery rate (%)
S.K. Park	3	0.334	0.045	0.081	24.25
S.D. Park	6	0.334	0.012	0.152	45.51
S.J. Park	6	0.334	0.01	0.053	15.87
G.S.W. Park	8	0.334	0.015	0.078	23.35
W.K Park	8	0.334	0.004	0.007	2.10
Average	6.20	0.33	0.02	0.07	22.22

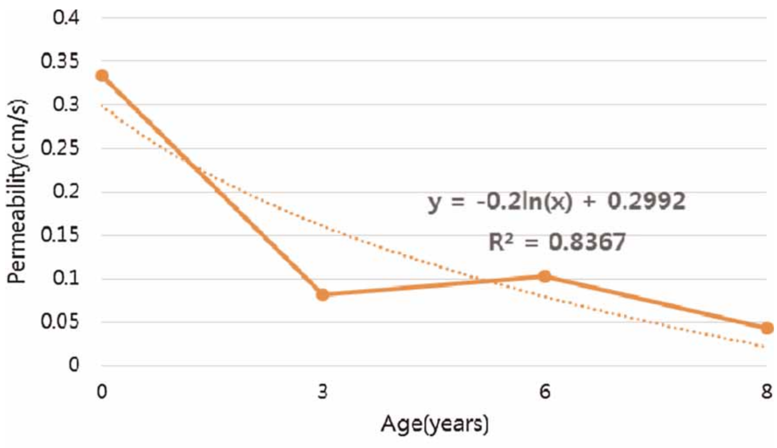

Figure 6 | Graph of Age vs. Permeability of UESF.

Table 3 | Coefficient of Restitution of G-blocks

Coefficient of restitution (%)	No. 1	No. 2	No. 3
Trial 1	21	22	22
Trial 2	21	25	26
Trial 3	23	21	21
Average	21.67	22.67	23.00

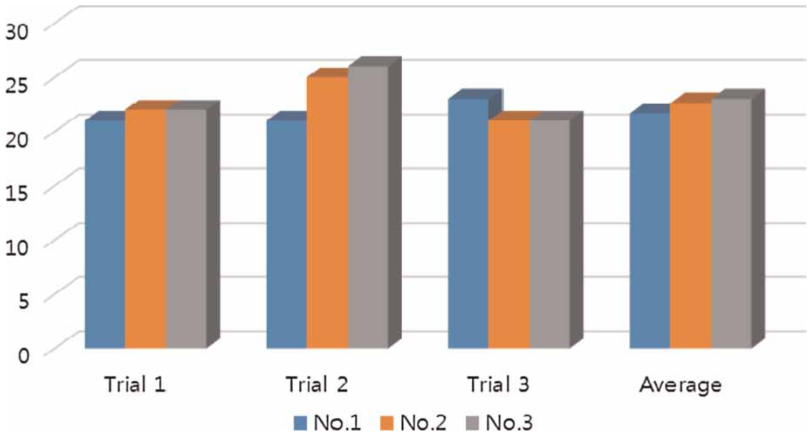

Figure 7 | Graph of Coefficient of Restitution of G-blocks.

Table 4 | Permeability of G-blocks

	Initial state	After pollution	After recovery	Recovery rate
No. 1	0.520	0.066	0.296	56.94
No. 2	0.511	0.065	0.281	54.96
No. 3	0.488	0.060	0.268	54.84
Average	0.506	0.064	0.281	55.60

Test results of G-block

Coefficients of restitution of three G-block specimen are 21.67, 22.67, and 23%.

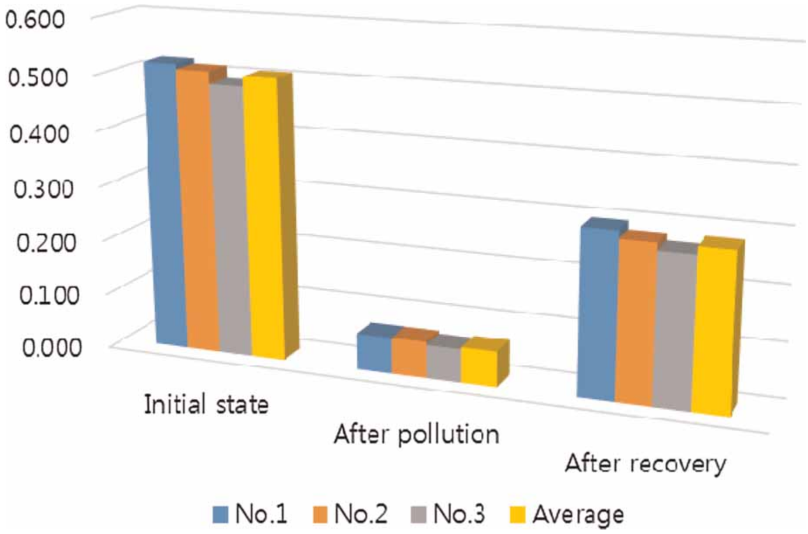

Figure 8 | Graph of Permeability of G-blocks.

The average permeability of three G-blocks in initial state was 0.506 cm/s, and it decreased to 0.064 cm/s after pollution with loses, which is equivalent to 88% reduction. The average permeability after the recovery was 0.281 cm/s, which is equivalent to 55.6% recovery rate.

Comparison of UESF and G-block

Average coefficient of restitution is 22.45 and 13.08% for G-block and UESF, respectively. It is believed that such increase in restitution stems from PE rainwater drain box and HDPE support pad which provides significant flexural elasticity to the entire structure. Initial permeability of G-block is also 1.51 times higher than that of UESF because the mix ratio of EPDM rubber chips to binder is increased to 5:1 in G-blocks. Recovery rate of G-block is also 2.5 times higher than that of UESF, the result attributed to thickness of elastic porous layer (EPDM rubber chips + binder), degree of pollution, and the elasticity of structures. It is believed that the G-block's higher coefficient of restitution and shorter duration of exposure to surface pollutions results in higher recovery rate. Further studies on optimization of the thickness of elastic porous layer and the elasticity of entire structures will be needed.

Table 5 | Comparison of UESF vs. G-block

	UESF	G-block
Coefficient of restitution (%)	12.4	22.44
Permeability of initial state (cm/s)	0.334	0.506
Recovery rate (%)	22.22	55.6

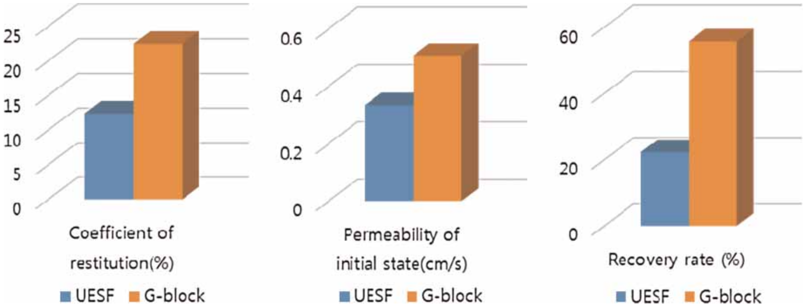

Figure 9 | Graph of data of UESF and G-block.

Development and application of G-block

Although the conventional rainwater drain box is used since G-block is only at the insipient stage of development, further research will devise its own drain box to improve serviceability and field applicability. Proposed design is described in Figure 10.

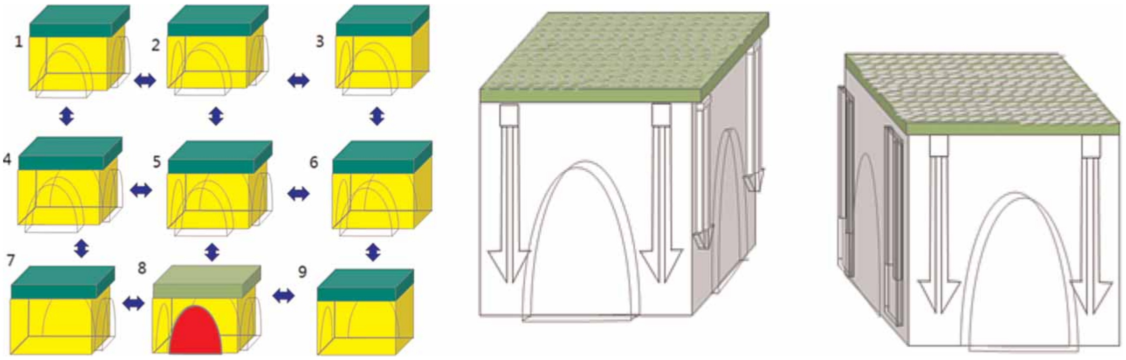

Figure 10 | Design Scheme of G-block installation.

In June 2013, the implemented G-blocks are applied and installed in Changwon and Jeonju test beds to verify their drain performance and recovery rate.

CONCLUSION

In this study, characteristics of UESF which is the urban rainwater infrastructure regeneration technology were tested. Based on the result, G-block was invented to serve transfer and storage functions. The result of test for UESF and G-block showed that thickness of EPDM permeable layer and the structure of layers affect coefficient of restitution. Therefore, the elastic characteristic of G-block can be adjusted properly according to the purpose of application. Permeability was recovered to at least 22.22% and at most 55.6% of initial permeability after permeability recovery with hammering equipment. The recovery is based on the elasticity of whole layers of the UESF and G-block. Permeability of G-block could be maintained high enough to treat urban rainwater through continuous management with hammering. Recovery rate is affected many design factors such as coefficient of restitution, thickness of the permeable layer, amount of binder, and so on. Therefore, further study on the relation between recovery rate and many design factors to develop G-block more applicable to urban rainwater treatment. As the result of the relation between age of UESF and permeability recovery rate showed that recovery rate decreased as age of UESF increased and the trend line showed that the UESF has sustainable permeability more than 10 years once installed.

Based on the result, G-block has enough economic feasibility and efficiency even if field experiment of G-block was not conducted. The invented G-block will be developed continuously and it is expected to contribute sustainable urban rainwater infrastructure regeneration.

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