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Experimentally based designing of rainwater runoff control for implementing of Rain Garden

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Abstract

This report shows that the basic approaches to be needed for implementation of rain garden as green infrastructure. The fundamental of green infrastructure including raingarden is described as replicating the natural hydrology and water balance to be achieved by measures i.e., infiltration, evapotranspiration, capture and reuse of rainwater. Then it is assumed that the raingarden technique mainly focused on infiltration to be achieved with a partially replacing soils in landscapes is easier acceptable measure to manage the extreme rainwater.

To develop an implementing process of rain garden, two tasks were provided: 1, selection of soils to be suitable for rain garden; 2, verification of infiltration capacity of rain garden structure to be proposed by mock-up test.

The characteristics of two soils to be selected for rain garden deliver the possibility of use for rain garden as follows.

a) Conditioned waterworks sludge:

Suitable for rain garden surface layer with vegetation planted areas.

b) Crushed clinker ash:

Material that can be used for rain garden without plants or as a drainage layer.

The observation result and data based on the mockup test demonstrated that the rain garden structure of which the double-layer consisted of two selected soils provides better performance than that of single layer of masa-do (decomposed granite soil)" used as well drained material, like a sandy medium, for landscape in the western region of Japan.

Keywords: Extreme rainfall event, Rainwater management, Reduction of rainwater runoff, Infiltration capacity of soil, Rain Garden, Selection of soil, Mock-up test

§1. Introduction

Global climate change brings multiple effects on the global and local environment, society, and economy. An excessive imbalance of rainfall events is counted among the influences of climate change of which it could be felt in the normal days in life. Basically, Japan as the eastern end of Asian monsoon has a plenty annual precipitation of which corresponds to be twofold of global average (880 mm/year). While at the same time, the trends of extreme rainfall have been clearly observed in a climate monitoring data in Japan. In long term aggregated data as 120 years (1901-2020), the annual number of days with rainfall more than 100 mm and 200 mm have significantly increased [1]. Whereas the annual number of days with rainfall more than 1 mm have significantly decreased. Such changes in rainfall events being extreme should make difficulty to control rainwater runoff, especially in the urbanized region with large area covered by impervious surface.

In recent years, a soil- and vegetation-based measures to manage extreme rainfall have been advocating in Japan. This kind of approach called as the green infrastructure could be expected as cost-effective, sustainable, and environmentally friendly measure. Because of the green infrastructures should be defined as and built as mimicking or restoring of natural hydrologic cycle of which includes infiltrate, evapotranspiration, capture and reuse of rainwater. Under present situation in Japan, the green infrastructures implementation is presumably in early stage to widespread use. Whereas under the condition of which the extreme rainfall and its threat are coming up to surface, the environmentally friendly measures are required to be developed and become widely used.

Then a raingarden technique might be easier acceptable measure to afford an extensive managing extreme rainwater, because of the raingarden cross-sectional structure with improved infiltration capacity would be installed as a partially replacing soils in landscapes, and hence applicable in both of existing planted area and newly landscaping area.

Therefore, in this research aimed to develop an implementing process of rain garden, two tasks were provided: 1, selection of soils to be suitable for rain garden; 2, verification of infiltration capacity of rain garden structure to be proposed by mock-up test.

§2. Selection of soils to be suitable for rain garden

The following two soil properties were assumed prior to seeking the soils to be suitable for rain garden structure i.e.

1, Porous medium with coarse-textured soil to allow high infiltration rate and adequate water retention required for plant growth, thus sandy medium may be excludable on this point

2, Medium to maintain an infiltration capacity against compacting pressure like the sandy mediums which are not necessarily negligible for rain garden use

Based on these assumptions, two materials of a conditioned waterworks sludge and a crushed clinker ash were selected among the commercial products referring to information on the brochures and websites.

Generally, the dewatered waterworks sludge originated from suspended solids in river water, have a good water and air permeability, because of its soil mass is hard to unstiffen via water resistance. Then water retentivity of dehydrated sludge could be ameliorable through an appropriate fracturing and size controlling process. Such a conditioned waterworks sludge had been picked up as the possible material to be used to rain garden.

Meanwhile, the other recycled material, crushed clinker ash has known as the porous medium with lower density than that of sand. Its lightweight and similar particle size distribution with sand can produce high infiltration rate and sand-replacing usability for raingarden structure.

Then next, the relationship between the compaction energy and the saturated hydraulic conductivity were investigated for two media to determine the adequateness as rain garden soil. A given amount of soil was put into plastic cylinder (inner diameter 50 mm) followed by a compaction with dropping of 2.5 kg rammer on the filled soil. The compaction energy was stipulated by the number of weight (water filled bottle or rammer) dropping. Then the saturated hydraulic conductivity of filled soil was measured as the permeability under condition of constant water head after water saturation of soil supplying from bottom of cylinder.

Fig.1 shows measurement results of the saturated hydraulic conductivity of each soil.

The permeability of conditioned waterworks sludge with no compaction corresponded to approximately to that of sand then decreased largely in response to the increasing compaction energy. Whereas The permeability of crushed clinker ash with no compaction was lower about 60% level of conditioned waterworks sludge, however it could maintain relatively higher permeability comparison with the trend of conditioned waterworks sludge.

The characteristics of these two soils described above and description in the brochure deliver the possibility of use for rain garden structure as follows.

a) Conditioned waterworks sludge:

Suitable for rain garden surface layer with vegetation planted areas.

Permeability like sand, but it must be noted that compaction reduces permeability markedly. Suitable for planting because of its high organic matter content bringing high fertilizer retention capacity.

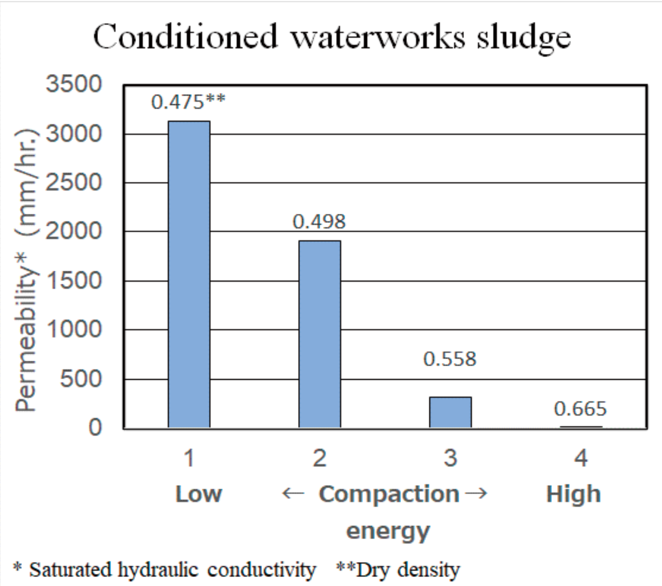
b) Crushed clinker ash: Material that can be used for rain garden without plants or as a drainage layer.

Same level of permeability as sand, and it can maintain permeability under increasing of compaction pressure.

Not suitable as a planting area due to its high pH and low level of organic matter.

§3. Verification of infiltration capacity of rain garden structure to be proposed by mock-up test

As described above, the rain garden mock-up test had been built to verify the infiltration capacity of rain garden structure consisted of two soils as double layer in which the conditioned waterworks sludge and the crushed clinker ash were used as upper and lower layer respectively. In this test, the infiltration capacity of double layer was compared to that of single layer with "masa-do (decomposed



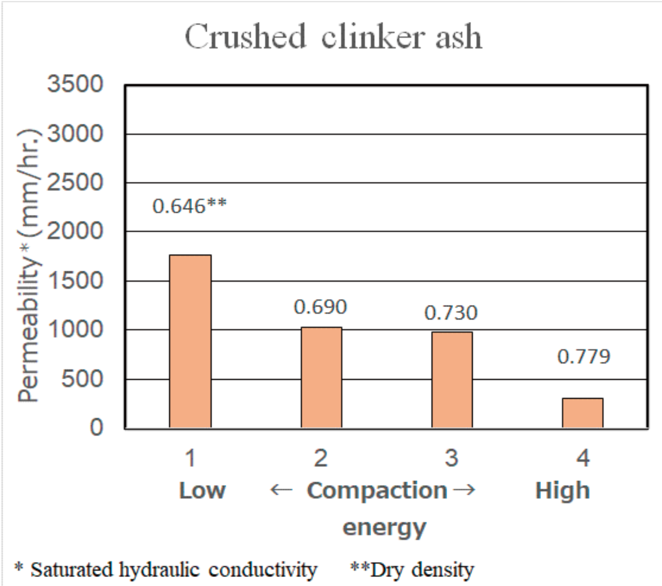


Figure 1. Changes of water permeability under different compaction conditions
1: Not compacted with weight (10 times tapping), 2: 35 kJ/m^3, 3: 140kJ/m^3, 4: 190 kJ/m^3

granite soil)" used as well drained material, like a sandy medium, for landscape in the western region of Japan.

3.1 Construction of rain garden mock-up

The mock-up of rain garden was installed as lysimeter facility to assess the infiltration capacity of cross-sectional soil structure built in it. More specifically, two rectangular soil tanks of 28 m3 volume (Inside dimension: Wide 2 m, Length 5 m, Height 1.4 m) soil tanks with drainage pipe on the bottom surface were constructed using a concrete brick. Fig.2 illustrates the cross section of one soil tank with rain garden structure. That structure consisted of double soil layer using selected two soils, conditioned waterworks sludge for upper layer of 30 mm and crushed clinker ash for lower layer of 200 mm respectively, was inserted into the left side of soil tank, and its surface was shaped like groove with 100 mm lower level to collect rainwater runoff from left area of soil tank surface.

Then other volume of that soil tank out of rain garden structure was filled with masa-do as reference soil (hereafter named as "rain garden section"). On the other hand, non-rain garden soil tank was filled using masa-do only that had the same shape groove as the rain garden section (hereafter named as "non-rain garden section).

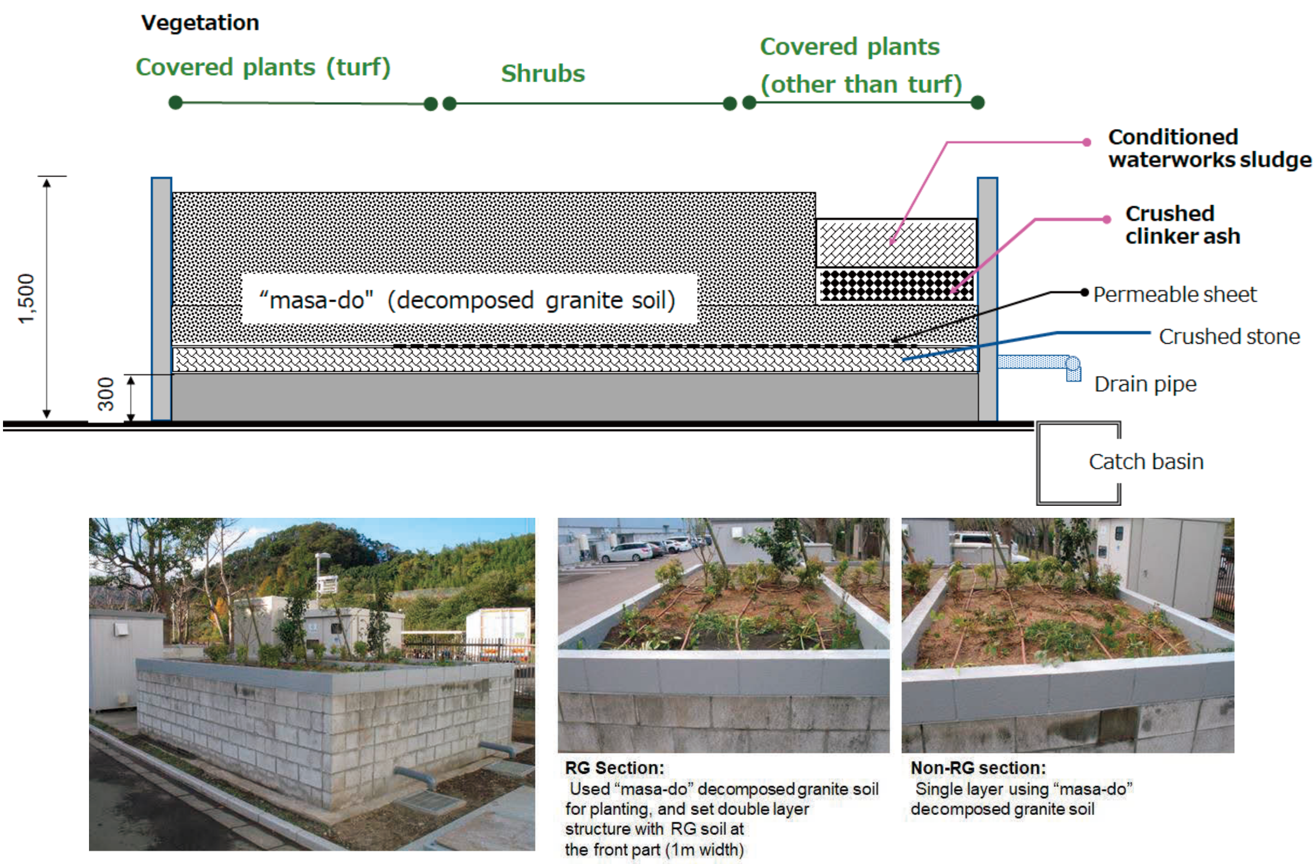


Figure 2. Mock-up of rain garden

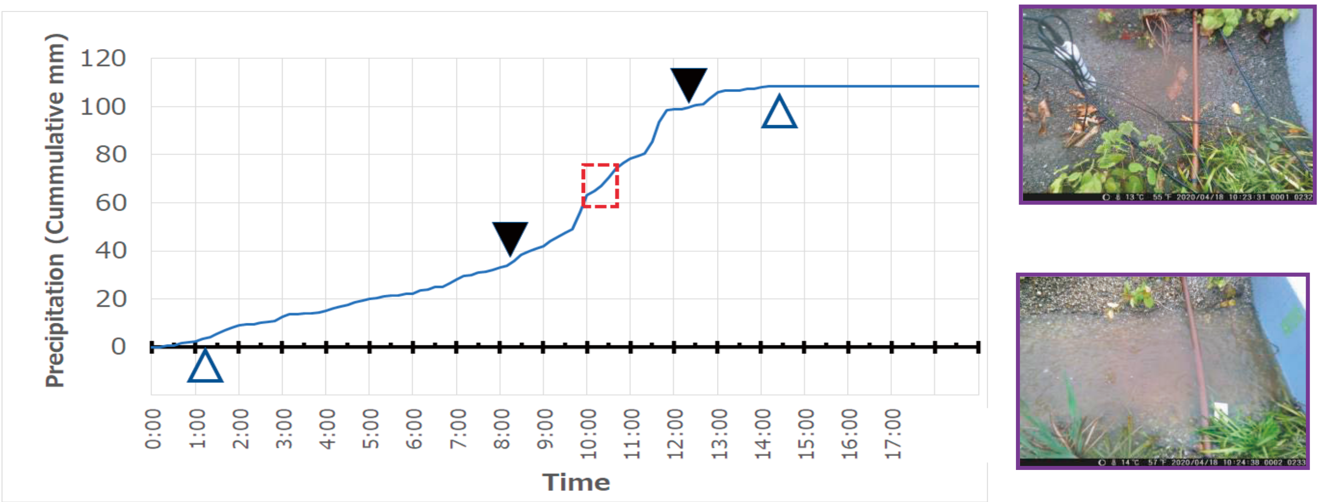


Figure 3. observation of puddle formation on the surface of soil

Up-pointing open triangles indicates continuous puddle formation on the non-rain garden section within a period between the triangles. Whereas down-pointing closed triangles indicates intermissive puddle formation on the non-rain garden section within a period between the triangles. Red doted box indicates period at a rainfall intensity of corresponding 37 mm/hr. Two photographs right side of graph were taken at that point, upper; rain garden section without puddle appearance, lower; non-rain garden section.

3.2 Results of RG mockup test (1): Under natural rainfall condition

To verify the ability to supress of the rainwater runoff on the rain garden section by comparison with the non-rain garden section, an observation of puddle formation on the surface of soil was conducted under natural rainfall event. The time-lapse cameras (400-CAM066, SANWA SUPPLY Co. Japan) were placed at the upper chest wall of soil tank to take a picture of groove-like shaped area of each section with 5 minutes interval.

The observation under cumulative precipitation 134 mm within 14 hours provided that the first puddle formation on the non-rain garden section appeared at cumulative precipitation of 3.5 mm. Whereas on the rain garden section, the puddle formation was not observed until cumulative precipitation reached 33 mm. The puddle on the non-rain garden section had appeared continuously

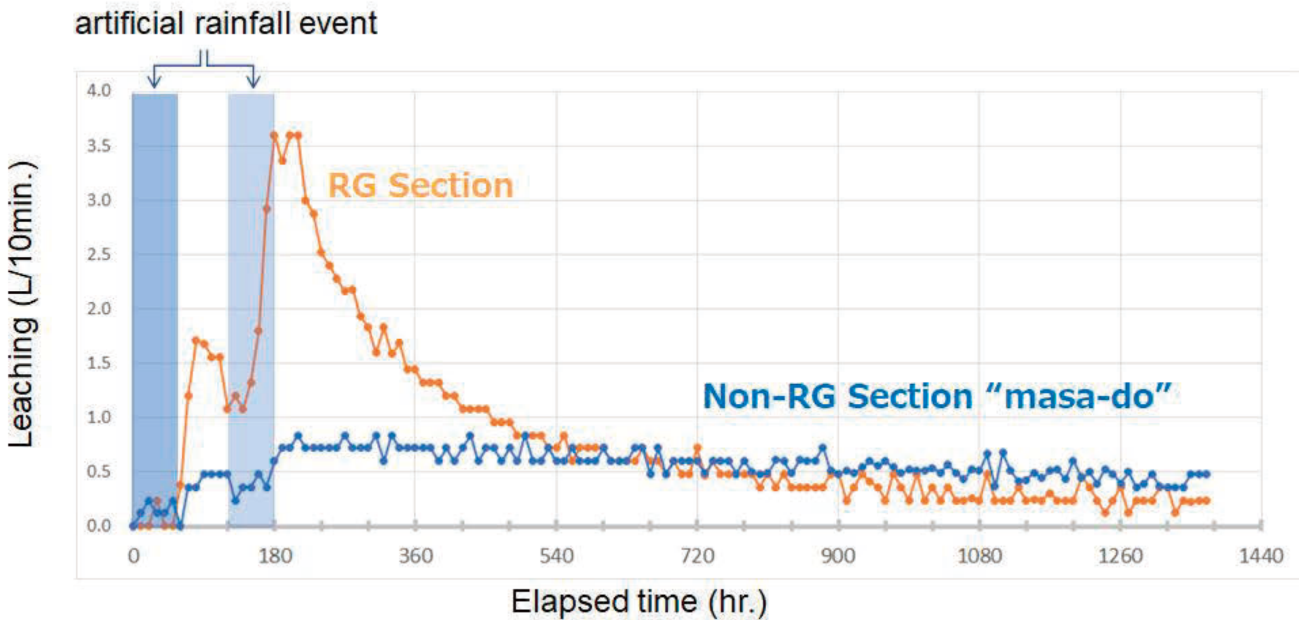


Figure 4. Comparison of leaching rate from drainpipe between the rain garden section and non-rain garden section ock-up of rain garden

until rain stopped, whereas that on the rain garden section was intermissive and turned to disappearance within a period of 30 minutes (Fig.3).

3.3 Results of RG mockup test (2): Under artificial rainfall condition

The above observation result of puddle formation on the rain garden section was directly evident reducing rainwater runoff in comparison with that on the non-rain garden section. Whereas to assess an infiltration capacity of rain garden structure, it is relatively difficult to produce a quantifiable evaluation on given soil layer under natural rainfall condition due to its instable intensity of rainfall.

Therefore, the infiltration capacity of soil layer on each section had been measured under an artificial rainfall condition. The self-made artificial rainfall equipment was installed at near side of groove shaped area of each section, and drainage water from pipe laid on the bottom of soil tank was collected into a plastic container. Then amount of drained water was measured as water rising using the level sensor (FL-001, KEYENCE Co., JAPAN) to be hold in the container.

Fig. 4 shows comparison of leaching rate from drainpipe between the rain garden section and non-rain garden section. The doble-layer consisted of two soils to be selected for rain garden section had provided approximately 6-fold higher leaching rate than that of single-layer of masa-do under this artificial rainfall test.

§4. Overview

The observation result and data based on the mockup test to be referred to above descriptions. The rain garden structure of which the double-layer consisted of two selected soils provides better performance than that of single layer of masa-do (decomposed granite soil)" used as well drained material, like a sandy medium, for landscape in the western region of Japan. This means the rain garden structure to be proposed based on the experimental results of this approach demonstrated high ability to reduce rainwater runoff.

The efforts of the people involved in the issue of climate change, will maintain lowering the risks including derived by extreme rainfall event. The implementation of the green infrastructure, one of such trials, could provide the countermeasures based on the natural hydrology and water balance.

References

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Short comment

The rain garden is way to address rainwater runoff as a sheet flow to be infiltrated into soil, unlike by a conventional piping and conveying. Thus, in the first phase of rain garden planning that a developing area should be partitioned into the watersheds based on a rational manner. Then experimentally based designing of rain garden should be ideally conjugated with a landscape design.

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