Study on Application of Recycled Aggregate in Sponge City Bioretention

Xi-juan XU¹, Ming-cheng ZHANG¹,* and Chao-xian DENG²

¹Xi'an Highway Research Institute, 710065, Xi'an, China
²Shaanxi Xixian New Area Fengxi new city development and construction (Group) Co., Ltd., 712000, Xi'an, China

*Corresponding author

Keywords: Recycled Aggregate, Sponge city, Bioretention.

Abstract. In recent years, it is more and more difficult to mine the natural aggregate, such as gravel. Through the comparative analysis of the material characteristics of recycled aggregate and natural gravel, such as water absorption, bulk density and crushing index, the experimental study shows that recycled aggregate is suitable for the construction of sponge city, and further introduces the structure and application advantages of the bioretention in sponge city, where recycled aggregate from construction waste is used. It is proposed that its construction technology, process, key points of construction quality control and subsequent maintenance management measures can provide reference for the application of recycled aggregate in bioretention in sponge city.

Introduction

In recent years, with the modernization of China's cities and the acceleration of rural urbanization, the amount of construction waste has increased, and the phenomenon of "Construction waste besieged the city" has become increasingly serious. As of the end of 2018, the amount of construction waste generated in China is about 1.7 billion tons. By 2020, 30 billion square meters of new residential buildings will be built. By then, the amount of construction waste generated in China will reach a peak and it is expected to exceed 3 billion tons. The vast majority of construction waste is treated by traditional open-air stacking or landfilling. This not only occupies a large amount of land, but also seriously damages the ecological environment. This is undoubtedly contrary to China's national policy of insisting on sustainable development and circular economy. The sponge city biological detention facilities in the construction of sponge cities generally use natural aggregates such as gravel or gravel. The acquisition of sand and gravel requires mountain quarrying and river excavation. For a long time, Mining sand and gravel has greatly damaged the ecological environment.

Characteristics Analysis of Recycled Aggregate

The main components of recycled aggregate are brick, concrete block and mortar block, as shown in Figure 1. Among them, the proportion of bricks and mortar blocks is relatively large, and the materials are loose, Porous, lightweight, low strength characteristics.

Figure 1. The main ingredients of recycled aggregate.
Water Absorption

Water absorption refers to the ability of the aggregate to absorb water at standard atmospheric pressure. Measured by the moisture absorbed by the aggregate and expressed as a percentage. The water absorption of the aggregate is determined by factors such as the number and size of the voids, the manner in which the particles are arranged with each other, whether the aggregate is easily wet, and the condition of excluding air from the voids. The water absorption test was conducted with reference to "Construction Stones and Pebbles" (GB/T14685-2011). The test objects were graded recycled coarse aggregate and natural coarse aggregate.

| Category         | 1h /% | 24h /% |
|------------------|-------|--------|
| Natural aggregate| 0.1   | 0.1    |
| Recycled aggregate| 14.0  | 15.2   |

The results of aggregate water absorption test showed that there was no change in the water absorption of natural aggregate at 1h and 24h, both were 0.1%; while the water absorption of regenerated aggregate at 1h was about 14% and the water absorption at 24h was about 15.2%. Natural crushed stone absorbs water to reach full saturation within 1h, and the water absorption of regenerated aggregate is a slow process. It gradually absorbs water from 1h to 24h until it reaches full saturation. It can be seen that the water absorption capacity of the recycled aggregate is 140 to 150 times that of the natural aggregate. Therefore, it can be used as a building material for the aquifer layer in the sponge city biological detention facilities, which has huge advantages and potential.

Bulk Density

Bulk density refers to the mass per unit volume of the bulk material in the bulk state. In addition to the particle density, it is also related to the particle size and its distribution and shape, especially the particle size distribution. Comparative analysis of the bulk density of recycled aggregate and natural crushed stone with different particle sizes. The specific test results are shown in Table 2.

| Particle size /mm | Recycled aggregate /g/cm³ | Natural aggregate /g/cm³ |
|-------------------|---------------------------|---------------------------|
| 4.75-9.5          | 1.00                      | 1.46                      |
| 9.5-19.0          | 1.26                      | 1.47                      |
| 19.0-31.5         | 1.27                      | 1.55                      |

It can be known from Table 2 that the bulk density of recycled aggregate and natural crushed stone of the same specification is obviously larger than that of recycled aggregate, mainly because the density of the bricks and cement mortar particles is relatively small. Therefore, when the aggregate is used in the sponge city biological detention facility, the unit volume of aggregate, recycled aggregate has the advantages of smaller weight and lighter weight than natural aggregate.

Crushing Index

The crushing value index refers to the performance index of the aggregate against crushing. The strength of the recycled aggregate can be expressed by the crushing value index. The aggregates with a particle size of 9.5mm-19.0mm are selected for the crushing index test. The test method is in accordance with "Construction Stones and Pebbles" (GB/T14685-2011).

| Category         | Recycled aggregate/% | Natural aggregate/% |
|------------------|----------------------|---------------------|
| Crushing index value | 28.8                | 18.7                |

It can be seen from Table 3 that the crushed value of the recycled aggregate is 28.8%, which is significantly higher than the natural aggregate of 18.7%, indicating that the strength of the recycled aggregate itself is lower than that of the natural aggregate. The main reason is that the strength of the
bricks and mortar particles in the recycled aggregate is low, and the mortar adhesion on the surface of the concrete block is weak, which results in the recycled aggregate being more easily broken than the natural aggregate. Although the strength of the recycled aggregate is lower than that of natural crushed stone, currently the recycled aggregate has been widely used in load-bearing structures such as road engineering. Given that there is no dynamic load on the upper part of the biological detention facility, it is a non-load-bearing structure facility, so it is completely feasible for use in drainage aquifers of biological detention facilities.

**Application Structure and Advantages of Biological Detention Facilities with Recycled Construction Waste Aggregate**

**Structure of Biological Detention Facilities**

Recycled aggregate is mainly used as drainage layer and water storage layer in biological detention facilities, which mainly replaces the gravel or gravel in traditional biological detention facilities. The structural layer is from plain to ground, the lower recycled aggregate layer, The structure diagram of the middle recycled aggregate layer, the upper recycled aggregate layer, the biological filter medium layer and the biological covering layer, which are specifically used in a rainwater garden or an ecological retention grass ditch, are shown in Figure 2.

![Figure 2. Structure of rainwater garden or ecological retention grass ditch.](image)

**Advantages of Sponge Urban Biological Detention Facilities with Recycled Construction Waste Aggregate**

The advantages of sponge urban biological detention facilities with recycled aggregates are mainly reflected in the following aspects:

1. The recycled aggregate layer includes the upper recycled aggregate layer (recycled aggregate with a particle size of 5 to 10 mm), the intermediate recycled aggregate layer (recycled aggregate with a particle size of 10 to 20 mm), and the bottom recycled aggregate layer (Recycled aggregate with a particle size of 30 ~ 50mm), and the particle size of the three aggregate layers changes from small to large. Therefore, the middle recycled aggregate layer is set to realize the transition between the upper recycled aggregate layer and the lower recycled aggregate layer. The interstices in the aggregate layer communicate with each other internally, which not only makes a reasonable connection from the particle size, but also allows the overall drainage of the recycled aggregate layer. The effect of water storage is greatly improved.

2. In the recycled aggregate layer, all recycled aggregates are used instead of natural aggregates such as gravel and crushed stone. The recycled aggregate has the characteristics of looseness, porosity, light weight, and good water permeability (storage), and its water absorption and drainage performance. And the water storage performance is much better than natural aggregates, which greatly improves the water seepage capacity, water storage capacity and water purification capacity of the obtained sponge city biological detention facilities.

3. The biological detention facility has a simple structure, convenient construction, low engineering cost, and low carbon and environmental protection.

4. All recycled aggregate aggregates are used in the recycled aggregate layer to make full use of the construction waste and turn the construction waste into a treasure, which not only solves the growing problem of "construction besieged city" in the city, but also reduces carbon emissions. Environmental
protection, reducing the environmental pollution caused by construction waste and land occupation occupying a lot of land resources, and solving the problem of the shortage of sand and stone materials in the construction of sponge cities, reducing the construction cost of sponge cities.

**Key Points of Construction Process and Construction Quality Control**

**Construction Process**

The construction process of the sponge urban biological detention facility with recycled aggregates is as follows:

**Measure and Pay Off.** According to the design width, the width of the upper opening of the groove of the biological retention facility is released, and the centerline and the sideline are sprinkled with white ash.

**Trench Excavation.** The trench is excavated by backhoe excavation and manual excavation, and earth excavation trucks are pulled out of the site. When there is an underground pipeline, manual excavation is used. After the excavation is completed, manual slope repair and trenching are performed. Pay attention to the trench width and trench depth when manually trenching, and hang the line fine.

When excavating the trench, first measure and locate the excavation line and mark the excavation line. After the line is checked for accuracy, the excavator should be used for excavation. When excavating, pay attention to retaining a protective layer of 20 cm above the elevation of the trench bottom. The compacted compactor is used to compact the base soil, and the compaction degree after compaction is not less than 93%.

**Artificial Slope Brushing.** First release the slope top pile and slope bottom pile, and hang the line according to the design elevation. Slope brushing is performed by mechanical and manual cooperation. First, the slope is mechanically brushed, and the slope is controlled by a slope rule according to the groove line. Then the slope is manually brushed. The excess earthwork on the slope shall be brushed to the slope angle from top to bottom, and the bottom slope angle line shall be cleared. The excess earthwork shall be piled up to both sides of the slope protection road, and all the spoil shall be transported to the spoil ground. If there is a lack of soil, take the same soil as the filler in the green belt to fill it, and then compact and shoot compactly. After the slope construction is completed, the slope rule should be used for timely inspection, and the deficiencies should be filled in time.

**Recycled Aggregate Layer under Paving.** The recycled aggregate layer is laid on the surface of the plain ground, and the recycled aggregate with a particle size of 30-50mm is used for laying. The appearance of the aggregate should be checked before laying to ensure that the appearance is clean, dry, weather-free, and free of impurities. It is uniform, and it is transported to the bottom of the trench manually when paving. First lay 8.5cm 30-50mm recycled aggregate in the trench of the biological detention facility, and then place the FH100 flexible water-permeable pipe (perforated drainage pipe) along the center of the groove. At the same time, it is possible to lay 30 ~ 50mm recycled aggregate on both sides and the upper part of the pipe until the thickness of the lower recycled aggregate layer is 30cm.

**Recycled Aggregate Layer During Laying.** The middle recycled aggregate layer is laid on the surface of the completed lower recycled aggregate layer, and the recycled aggregate layer with a particle size of 10 to 20 mm is selected for laying. The thickness of the middle recycled aggregate layer is 10 cm.

**Paved with Recycled Aggregate Layer.** The recycled aggregate layer is laid on the surface of the completed recycled aggregate layer, and the recycled aggregate layer with a particle size of 5-10 mm is selected for laying, and the laying thickness of the upper recycled aggregate layer is 5 cm.
Laying Biological Filter Media Layer. After the regeneration aggregate layer is laid, a biological filter medium layer with a thickness of 60 cm is laid on the surface. The material of the medium layer can be a mixture of coarse sand, soil and coconut bran. Before construction, 40% coarse sand (fineness modulus requirement is 3.7-3.1, average particle size is above 0.5mm), 40% raw soil and 20% coconut bran are evenly mixed by mixing equipment and transported to the trench on the construction site. At the side of the groove, the mixed material after mixing should have a good gradation, a uniform composition, and the best water content. The artificial backfill is 5cm higher than the groove design elevation.

Planting Biological Cover. A bio-covering layer with a thickness of 60 mm is planted on the surface of the biological filter medium layer, and flood-tolerant and drought-resistant plants such as miscanthus, reed bamboo, pennisetum or cannabis can be planted, as well as plants such as regular flowers and plants.

Artificial Slope Repair. After the construction of the slope is completed, it should be leveled by pulling lines. The places above the standard elevation should be repaired in time. The places below the standard elevation should be leveled and rammed to make the slope of the brushed slope smooth.

Key Points of Construction Quality Control
(1) The allowable deviation of the thickness of the recycled aggregate layer is -10mm. The inspection method uses observation inspection and steel rule measurement;
(2) The drilling rate of perforated PVC drainage pipes shall not be less than 95% of the design requirements. The inspection method is carried out by observation inspection.

Conclusion
Compared with natural aggregates, recycled aggregates have their unique advantages. They are loose, porous, and lightweight. These characteristics are especially suitable for sponge city's requirements for building materials. After using recycled aggregates, the sponge city's biological detention facilities can absorb water and store water. Capacity and water seepage capacity have been improved. The recycled aggregate is used in the sponge city biological detention facility. By setting up three layers of recycled aggregate, the particle size is reasonably connected and unloaded, so that the overall water seepage and water storage effect of the recycled aggregate layer are greatly improved. Its simple structure, convenient construction method, and low production cost. At the same time, it uses recycled aggregates to replace natural aggregates such as limestone and gravel, and turns waste into treasure. It is low-carbon and environmentally friendly, which solves the problem of "construction siege of the city" and has social benefits. The economic and environmental benefits are huge, and they have great prospects for promotion and application, which are worthy of promotion and application in the construction of sponge cities in China.

References
[1] Jun Ying, Zhang Qing-ping, Application Research of Urban Permeable Pavement under the Sponge City Concept, Modern Urban Research, 2016 (7)41-46.
[2] Xian Li, Yue Zhang, Jia-long Chen, Research on water storage capacity of recycled aggregate water storage layer in sponge city construction, China Water & Wastewater, 2016, 32 (3)86-88.
[3] Kong-jian Yu, Di-hua Li, Hong Yuan, Theory and Practice of "Sponge City", Urban Planning, 2015, 39 (6)26-36.
[4] Jia-long Chen, Current Status and Suggestions on the Utilization of Construction Waste Resources in China, Construction Science and Technology, 2014 (1)9-12.
[5] Mao-sen Ju, Thoughts on sponge city construction concept, technology and policy issues, Research on Water Resources Development, 2015 (3)7-10.
[6] China National Standardization Administration Committee. GB/T14685-2011 Crushed Stone and Pebble for Construction, Beijing: China Standard Press, 2011.